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SURVEY OF SEA STRAIT DATA AROUND JAPAN.(U)

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CONTRACT ONR N00014-80-C-0039
TEKMARINE PROJECT TCN-003

SEA STRAITS RESEARCH

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BY CHOULE J. SONU

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TEKMARINE, INC.

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COASTAL SCIENCES PROGRAM
OFFICE OF NAVAL RESEARCH
ARLINGTON, VIRGINIA 22217

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ACKNOWLEDGEMENTS

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Mrs. Anina Gadd, Ms. Christina Sonu and Mr. Yutaka Ochi spent many dedicated hours in preparing the figures and tables and otherwise performing numerous chores for the report. The author's acknowledgements are also due to Mrs. Toni Simms of Tekmarine who was responsible for typing, editing and collating the report.

Choule J. Sonu

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1. INTRODUCTION

1.1 Objective

The principal objective of this study is to review and consolidate existing oceanographic information relating to three major sea straits around Japan. These sea straits are:

- o Tsushima Strait (or Korea Strait),
- o Tsugaru Strait, and
- o Soya Strait (or La Perouse Strait)

The locations of these sea straits are shown in Figure 1-1.

More specifically, the study called for compiling the following products:

1. <u>Data Inventory System</u>
   - o Search and review oceanographic data existing in scattered sources.
   - o Organize a computer-based directory of the reviewed data.
2. <u>Descriptive Oceanography</u>
   - o Review existing literature.
   - o Prepare a descriptive summary of the state of knowledge on major oceanographic processes.
3. <u>Annotated Bibliography</u>
   - o Identify mile-stone papers and reports.
   - o Prepare annotations on the selected literature.

Key oceanographic parameters included in this study are sea water temperature, salinity, and currents, and to a lesser extent, tide.

Numerous agencies and academic organizations in Japan and Korea are engaged in the collection of oceanographic data in waters adjacent to Tsushima, Tsugaru and Soya Straits. While the amount of data being collected in this region has been increasing sharply in recent

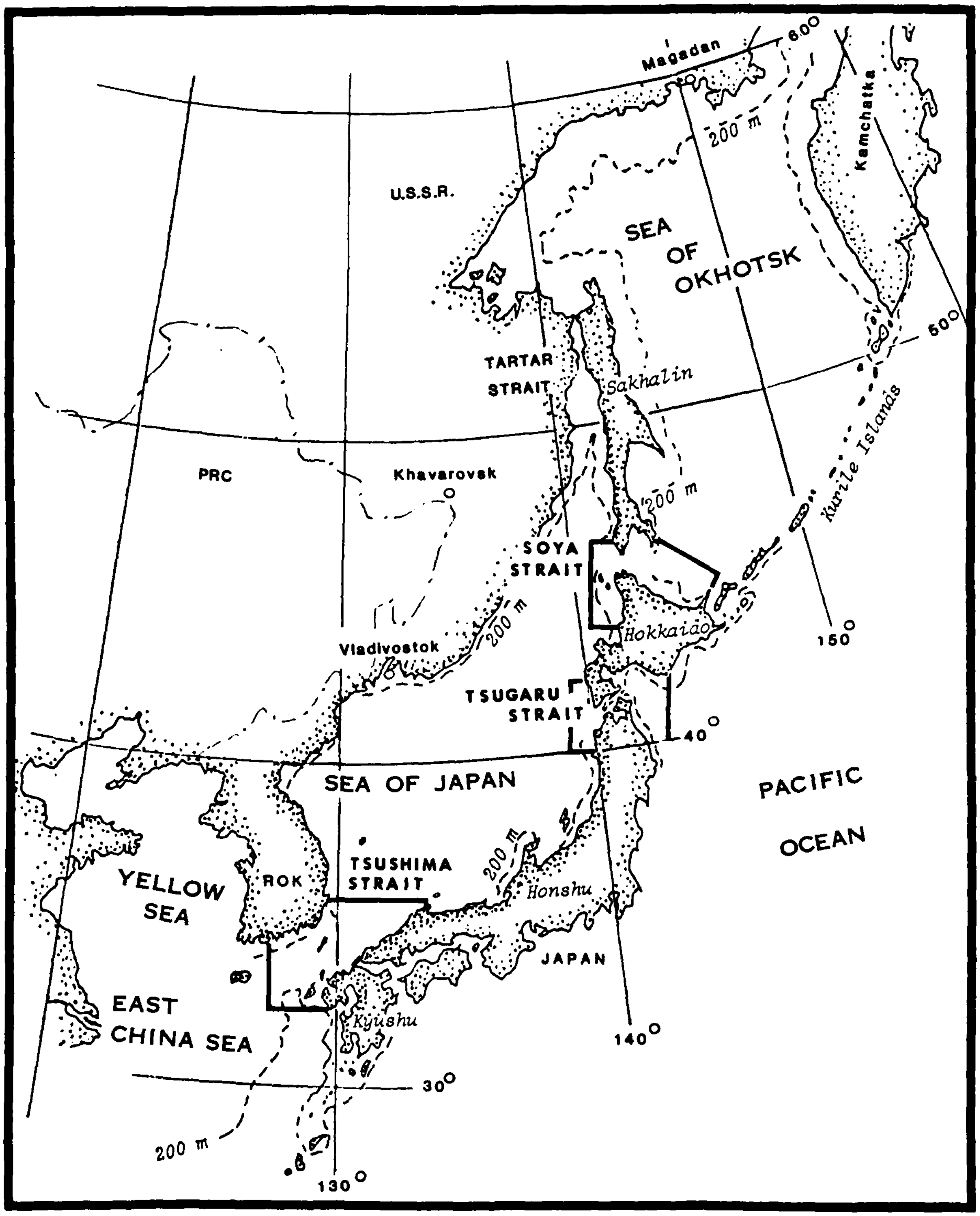

Figure 1-1. Areas of Interest.

years, efforts to consolidate the accumulating data into a central archive or directory have been lacking. This report is an attempt to fill such a vacuum by organizing a data directory system which would provide:

1. Data inventory information to managers and planners, and

2. a referral guidance for those who wish to access or retrieve data.

Although the enormity of data volume and the numerous scattered presence of data sources made it virtually impossible to identify and review all the existing data, much effort was made in this study to carry out an exhaustive survey on the principal data sources in Japan and Korea.

In this report, the inventory information was organized in accordance with the cruise inventory format of "Oceanographic Environmental Reference Service" (OERS) system, a computer-based reference system developed at the Naval Oceanographic Office and sponsored by Commander, Naval Oceanography Command. Established as a twin system along with "Coastal Environmental Reference Service" (CERS) under "Oceanographic Management Information System" (OMIS), the OERS data base is implemented under a UNIVAC software package known as DMS-1100.

The OERS provides "reference information" on data rather than the data per se. Standard data base elements in the OERS cruise inventory include identification of sea strait (called project), cruise number code, sponsoring organization, ship's name, data collection dates, identification of general ocean area, type(s) of marine zone, coordinating agencies, data exchange availability, scientist(s) in charge and his address. However, in order to enhance the information content in the data base, we have also added an annotation describing specific localities of cruise, published oceanographic data reports and the holding libraries, amount of cruise stations by parameter, and other necessary comments. Thus, our enhanced cruise inventory contains not only information on data collection activity but also on data volume.

The user can access the OERS data base either by cruise, parameter, water body, or global coordinates (WMO area identifier). In order to further assist the user in accessing the data base, this report contains additional material for orientation:

- A complete summary of plotted cruise tracks by the three most important data collecting agencies in Japan (Hydrographic Office, Fisheries Agency, and Meteorological Agency), is provided in Appendices 1, 2, and 3. A potential user may first thumb through these cruise tracks to gain a swift preliminary assessment of the existing data volume in a specific area of interest.

- Statistical summary of cruise stations by area, parameter, and agency is provided in Chapter 3.4: "Overview of OERS Cruise Inventory on Japanese Sea Straits."

- Major data collectors in Japan and Korea, along with their geographical jurisdictions, survey ships, and data volume, are described. (See Chapter 1.3: "Principal Data Collectors" and Chapter 1.4: "Tide and Tidal Currents").

- A detailed chronology of principal oceanographic events relating to oceanographic data collection practices in Japan and Korea, including institutional evolutions and major programs, is presented. (See Chapter 2.1: "Historical Perspective").

- Recent patterns and trends in the data collecting practices in Japan and Korea are discussed. (See Chapter 2.2: "Patterns and Trends").

- Current status of data archiving effort is reviewed, with special emphasis on the Japan Oceanographic Data Center. (See Chapter 2.3: "Status of Data Archiving").

- A descriptive oceanography relating to the Tsushima, the Tsugaru, and the Soya Straits is presented to identify the current state of knowledge. (See Chapter 3: "Descriptive Oceanography").

- An annotated bibliography is prepared to outline representative research efforts on the three sea strait regions. (See Chapter 4: "Annotated Bibliography).

1.2 Areas of Interest

All the three sea straits named for study have one conspicuous aspect in common: they are the principal passages of the Tsushima Warm Current.

The Tsushima Warm Current enters into the Sea of Japan from the East China Sea through the Tsushima Strait. After flowing into the Sea of Japan and subsequently moving northward along the northwestern coast of Honshu (the main island of Japan), the Tsushima Warm Current discharges much of its transport into the Pacific Ocean through the Tsugaru Strait and the remainder into the Sea of Okhotsk through the Soya Strait.

Figures 1-2(A), (B) and (C) present the boundary of the areas of interest employed in this report. Because of the dominant role of the Tsushima Warm Current in characterizing the dynamics in the sea straits under study, it was necessary to consider (1) upstream region, (2) channel region, and (3) downstream region for each area of interest. Thus, involved in this study are four distinct bodies of water: East China Sea, Sea of Japan, Sea of Okhotsk, and Pacific Ocean.

In the Tsushima Strait (Figure 1-2(A)), the boundary extends to the southern tip of Nagasaki Prefecture of Japan and Yosu of the Republic of Korea in the East China Sea, and to the eastern tip of Shimane Prefecture of Japan and Pohang of the Republic of Korea in the Sea of Japan.

In the Tsugaru Strait (Figure 1-2(B)), the boundary extends to Cape Nyudozaki on the south and Okushiri Island on the north in the Sea of Japan, and to Cape Erimo Misaki on the north and Kuji on the south in the Pacific Ocean.

In the Soya Strait (Figure 1-2(C)), the boundary on the Japan Sea side extends between Rumoye of Hokkaido and Nevel'sk of Sakhalin, and on the Sea of Okhotsk side between Cape Shiretoko of Hokkaido and Cape Aniva of Sakhalin.

In this report the following uniform terminology is employed.

Tsushima Strait - Both the Koreans and Russians use the term "Korea Strait", whereas the Japanese tend to distinguish the west channel as "Korea Strait" and the east channel as "Tsushima Strait." In this report, "Tsushima Strait" is used to include both channels.

Soya Strait - The term "Soya" is a Japanese word, whereas the term "La Perouse" is as widely used, especially by the Russians. John Bartholomew's "Advanced Atlas of Modern Geography" uses the former, while the National Geographic Society's "Atlas of the World" uses the latter. In this report, a term "Soya Strait" is employed.

Sea of Japan - Whereas the Koreans still preper a term "Eastern Sea", the term "Sea of Japan" has gained a dominant popularity in the international community. This term is also used by Defense Intelligence Agency DIAM 65-18 (Geopolitical Data Elements and Related Features). In this report, a term "Sea of Japan" is employed.

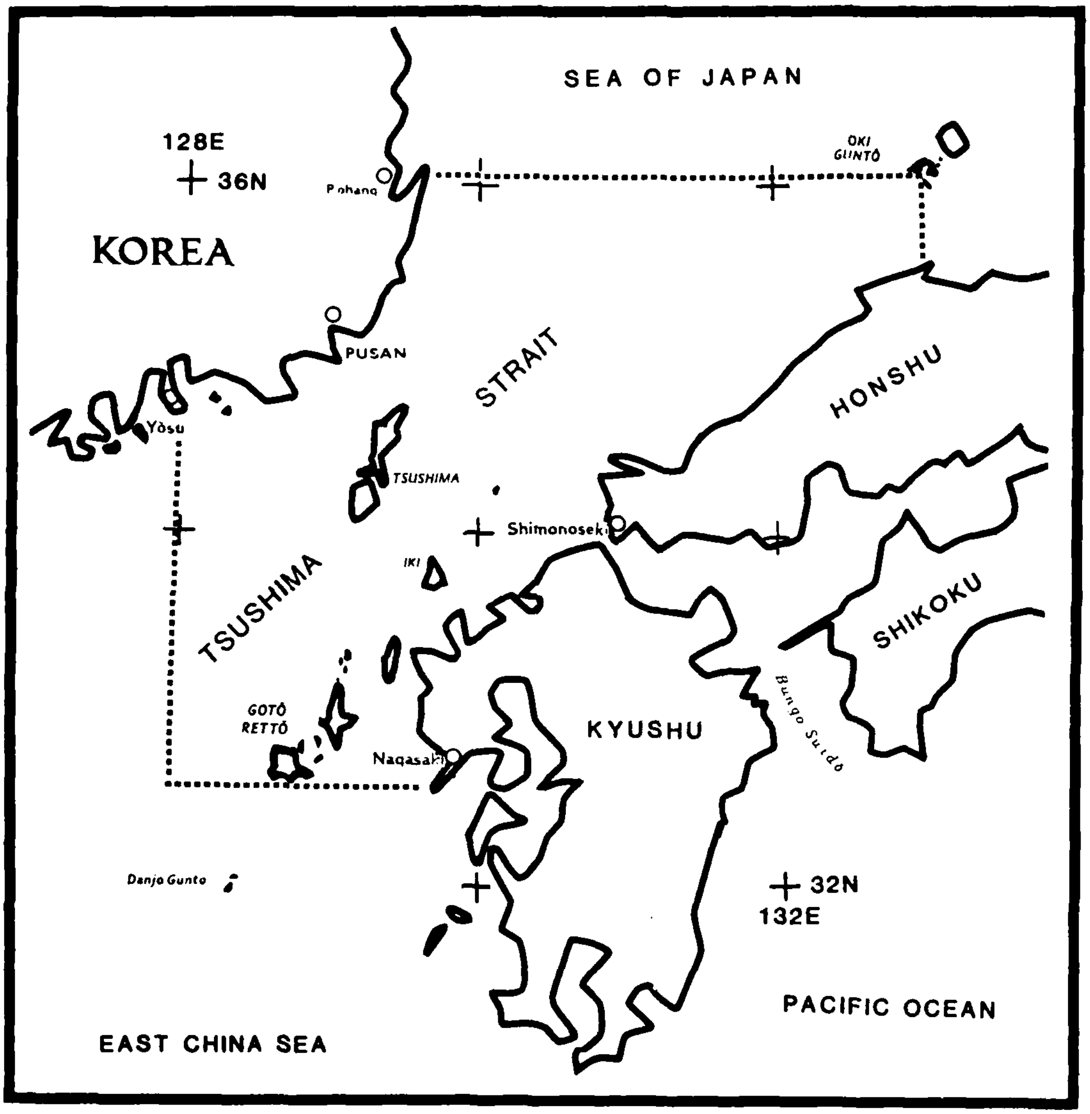

Figure 1-2(A). Boundary of the Tsushima Strait region.

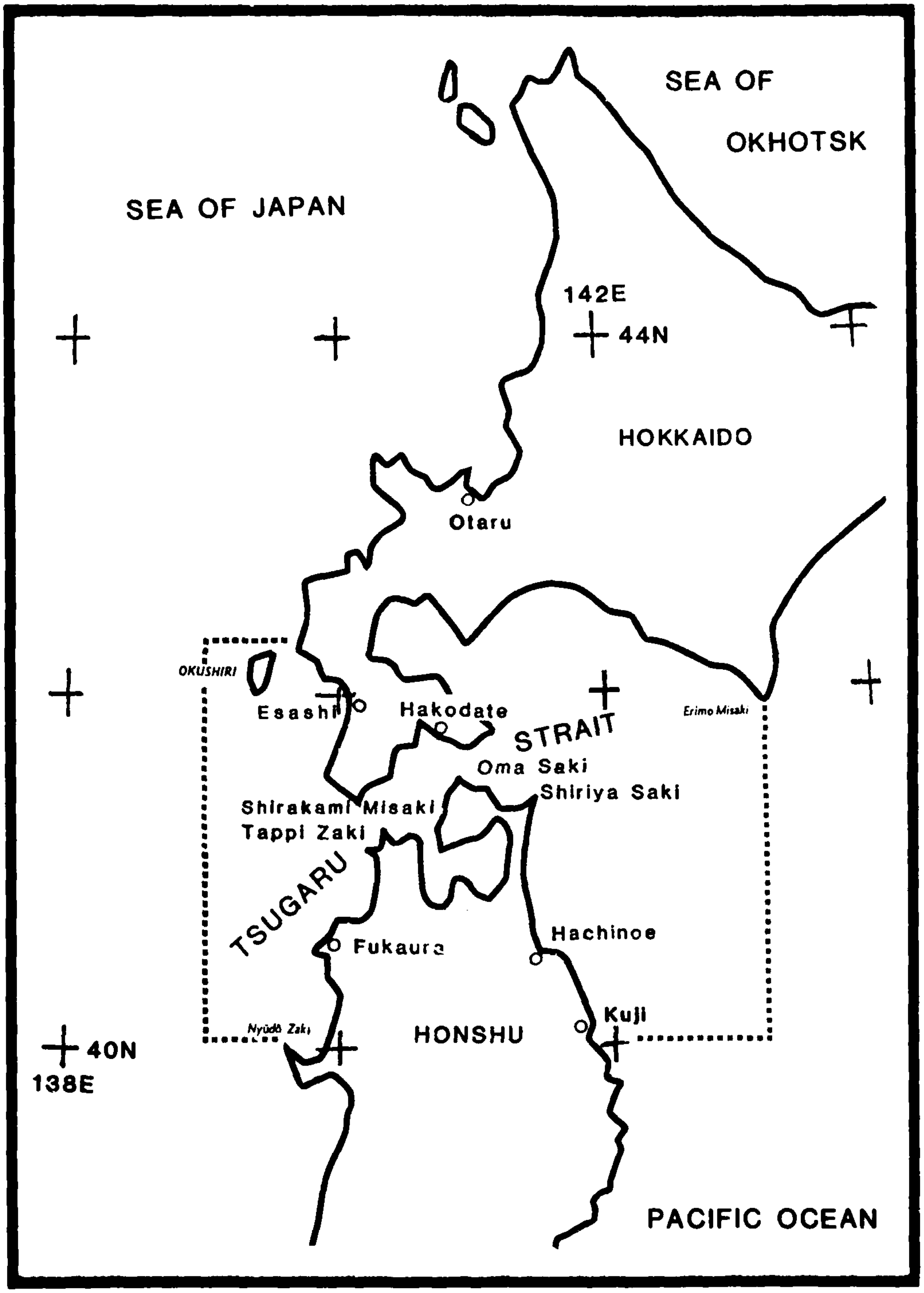

Figure 1-2(B). Boundary of the Tsugaru Strait region.

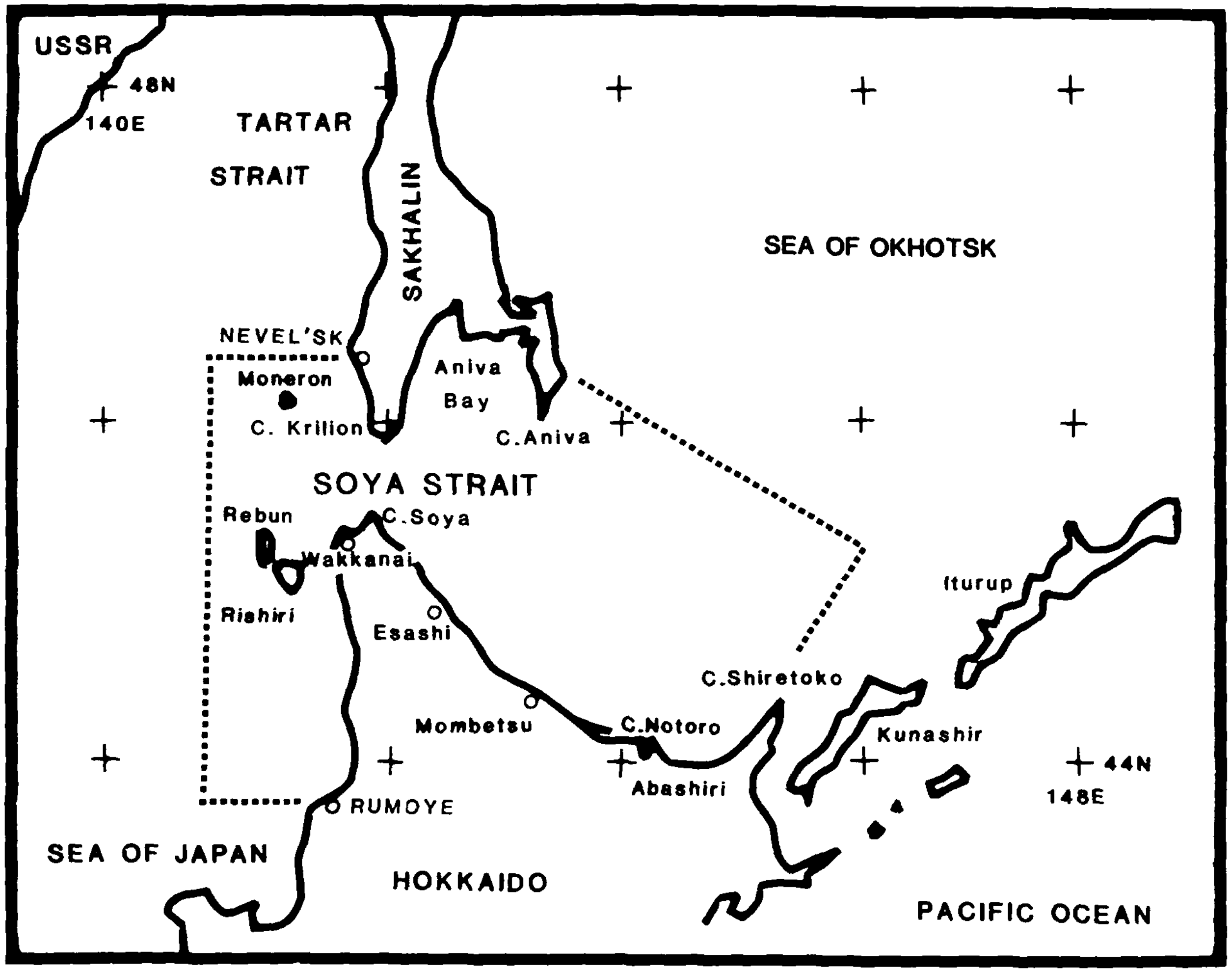

Figure 1-2(C). Boundary of the Soya Strait region.

1.3 Principal Data Collectors

Table 1-1 summarizes oceanographic data collectors in Japan and Korea and the range of oceanographic data types being studied by these agencies. The data type of particular interest to this study is the serial oceanographic data. Serial observations are usually conducted on an established schedule along fixed survey tracks, and usually such parameters as sea water temperature, salinity, D.O., nutrient salts, and p.H. are measured at standard depths. Also, a GEK measurement of surface current is becoming a routine practice in the serial observations in Japan.

The agencies which account for significant amounts of serial oceanographic data relating to sea straits are summarized in Table 1-2. These are:

<u>Japan Hydrographic Office</u>, Maritime Safety Agency, Ministry of Transport, with its headquarters in Tokyo and a total of 11 regional offices, of which 5 (plus the headquarters) operate in the vicinity of sea straits.

<u>Japan Fisheries Agency</u>, Ministry of Agriculture, Forestry and Fisheries, with its 7 regional Fisheries Research Laboratories, of which 4 operate in the vicinity of sea straits.

<u>Japan Meteorological Agency</u>, with 4 Marine Meteorological Observatories, of which 3 (plus the headquarters) operate in the vicinity of sea straits.

<u>Prefectural Fisheries Experiment Stations</u>, of which 11 stations operate in the vicinity of sea straits.

<u>Korea Fisheries Research and Development Agency</u>, with its headquarters in Busan and a total of 8 branch offices. Only the headquarters is associated with serial oceanographic observations, its jurisdiction covering the Yellow Sea and the Sea of Japan.

<u>Korea Hydrographic Office</u>, Ministry of Transport. The KHO is responsible for serial observations in the vicinity of the Tsushima Strait (along Lines 200 series).

For locations of various place names, see Figure 1-3.

		COASTAL GEOGRAPHY, BATHYMETRY, GEOLOGY	MARINE GEOLOGY, GEOPHYSICS	SEDIMENT	OCEAN WAVE	TIDE	TIDAL CURRENT	OCEAN CURRENT, SEA TEMPERATURE	SERIAL OCEAN. SURVEYS	SEA FOG	SEA ICE
JAPAN	HYDROGRAPHIC OFFICE	*	*	*		*	*	*	*		
	METEOROLOGICAL AGENCY				*	*			*	*	*
	FISHERIES AGENCY							*	*		
	SELF-DEFENSE AGENCY							*	*		
	GEOLOGICAL SURVEY		*	*							
	GEOGRAPHICAL INSTITUTE	*				*					
	PORTS/HARBORS BUREAU				*	*			*		
	HOKKAIDO DEV. AGENCY				*	*	*				
	OKINAWA DEV. AGENCY				*	*	*				
	UNIVERSITIES		*	*				*	*		*
KOREA	FISH. RESEARCH & DEV. AGENCY					*	*	*	*		
	HYDROGRAPHIC OFFICE	*	*	*		*	*	*	*		
	OCEAN RESEARCH & DEV. INSTITUTE	*				*	*	*			
	MARITIME & PORT ADMINISTRATION				*	*	*				
	UNIVERSITIES				*			*			

TABLE 1-1. Data types versus corresponding data collectors.

TABLE 1-2: Principal agencies engaged in serial oceanographic observation.

REGION	OFFICE	INVENTORY CODE	RELEVANT SEA STRAIT
JAPAN HYDROGRAPHIC OFFICE			
Headquarters	Tokyo	-0	All waters.
Region No. 1	Otaru	-1	Tsugaru & Soya, both up- & down-stream.
No. 2	Shiogama	-2	Tsugaru, mainly downstream and off Sanriku coasts.
No. 3	Yokohama	-3	Pacific Ocean.
No. 4	Nagoya	-4	Pacific Ocean.
No. 5	Kobe	-5	Pacific Ocean.
No. 6	Hiroshima	-6	Seto Inland Sea.
No. 7	Kitakyushu	-7	Tsushima, upstream on East China Sea.
No. 8	Maizuru	-8	Tsushima, downstream on Sea of Japan.
No. 9	Niigata	-9	Tsushima downstream and Tsugaru upstream, on Sea of Japan.
No.10	Kagoshima	-10	Pacific Ocean & East China Sea.
No.11	Naha	-11	Pacific Ocean & East China Sea.
JAPAN FISHERIES AGENCY			
Headquarters	Tokyo		Administrative.
Fisheries Research Laboratory			
Hokkaido	Yoichi	FAH	Tsugaru & Soya, both up- & down-stream.
Tohoku	Shiogama	FAT	Tsugaru, downstream on Pacific Ocean.
Tokai	Tokyo	-	Pacific Ocean.
Nankai	Kochi	-	Pacific Ocean.
Seikai	Nagasaki	FAS	Tsushima, upstream on East China Sea.
Nihonkai	Niigata	FAN	Tsushima, downstream on Sea of Japan.
Naikai	Hiroshima	-	Seto Inland Sea.

(TO CONTINUE)

TABLE 1-2: Principal agencies engaged in serial oceanographic observation. (Cont'd)

REGION	OFFICE	INVENTORY CODE	RELEVANT SEA STRAIT
JAPAN METEOROLOGICAL AGENCY			
Headquarters	Tokyo	MAQ	All waters.
Marine Meteorological Observatory			
Hakodate	Hakodate	MAH	Tsugaru & Soya, downstream on Pacific Ocean and Sea of Okhotsk.
Kobe	Kobe	MAK	Mainly, Pacific Ocean.
Nagasaki	Nagasaki	MAN	Tsushima, upstream on East China Sea.
Maizuru	Maizuru	MAM	Tsushima, downstream on Sea of Japan.
PREFECTURAL FISHERIES EXPERIMENT STATIONS			
Hakodate	Hakodate	FKH	Tsugaru, up- & down-stream. Soya upstream.
Wakkanai	Wakkanai	FKW	Soya, channel and downstream.
Abashiri	Abashiri	FKA	Soya, downstream.
Kushiro	Kushiro	FKK	Tsugaru, far downstream.
Chuo (Hokkaido)	Yoichi	FKC	All waters around Hokkaido.
Aomori	Nishi-Tsugaru	FKA	Tsugaru, up- and down-stream.
Nagasaki	Nagasaki	FKN	Tsushima, far upstream on East China Sea.
Saga	Karatsu	FKG	Tsushima, upstream on East China Sea.
Fukuoka	Fukuoka	FKF	Tsushima, immediately upstream and channel.
Yamaguchi	Nagato	FKY	Tsushima, channel and immediately downstream on Sea of Japan.
Shimane	Hamada	FKS	Tsushima, far downstream.

(CONTINUED)

TABLE 1-2: Principal agencies engaged in serial oceanographic observation. (Cont'd)

REGION	OFFICE	INVENTORY CODE	RELEVANT SEA STRAIT
KOREA FISHERIES RESEARCH & DEVELOPMENT AGENCY			
Headquarters	Busan		Yellow Sea (Serial Lines Series 100) & Sea of Japan (Series 300), downstream of Tsushima Strait.
Branches			
Inchon	Inchon		Local, Yellow Sea.
Gunsan	Gunsan		Local, Yellow Sea.
Mogpo	Mogpo		Local, Yellow Sea.
Yosu	Yosu		Local, East China Sea.
Chungmu	Chungmu		Local, East China Sea, upstream of Tsushima West Channel.
Jeju	Jeju		Local, East China Sea, upstream of Tsushima West Channel.
Pohang	Pohang		Local, Sea of Japan.
Jumunjin	Jumunjin		Local, Sea of Japan.
KOREA HYDROGRAPHIC OFFICE			
Headquarters	Seoul, Busan		Tsushima, up- and down-stream.

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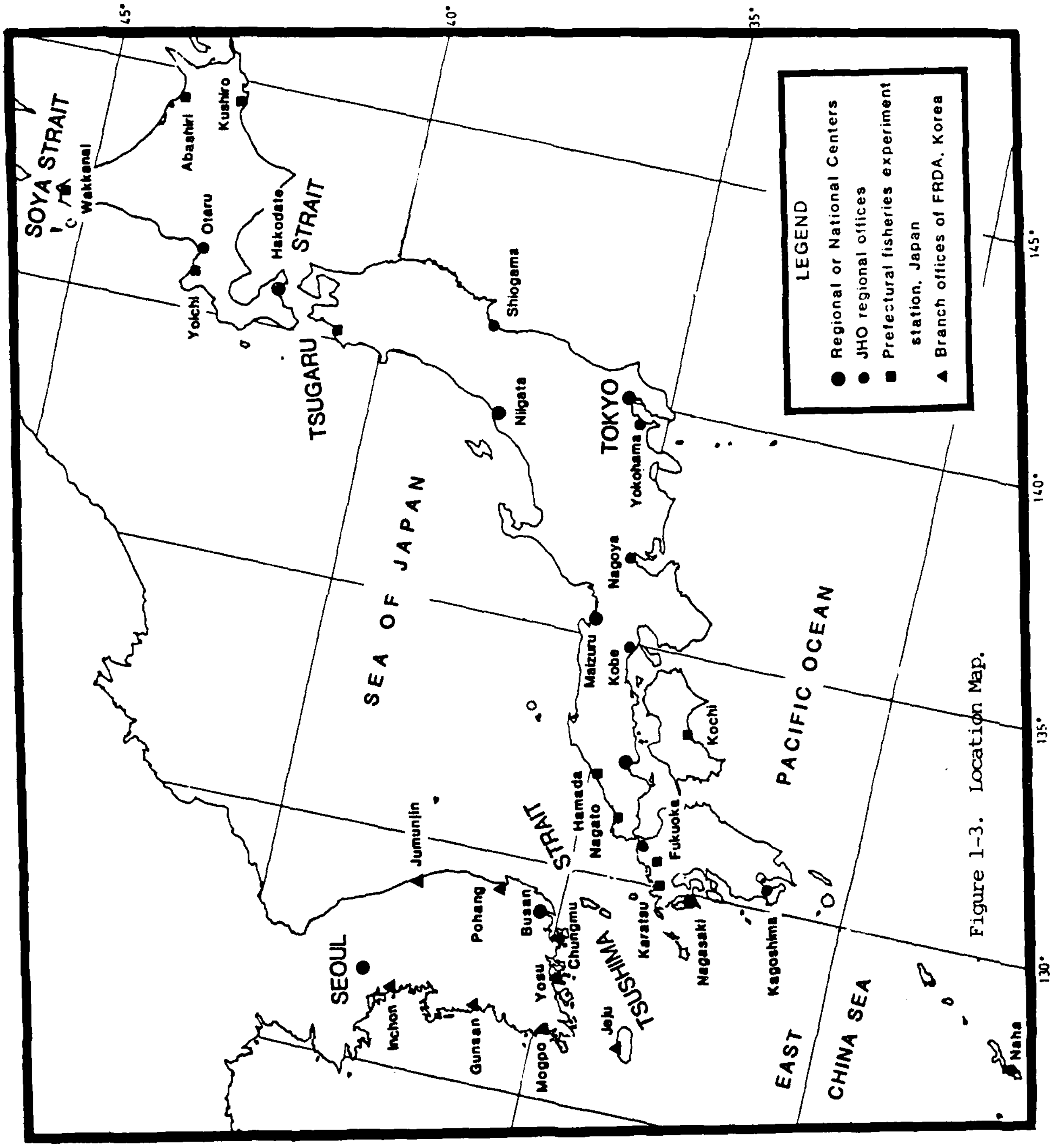


Figure 1-3. Location Map

Typical cruise tracks of these agencies are shown in Figures 1-4, 1-5, 1-6, and 1-7. Table 1-3 lists coordinates of the serial stations under KFRDA and KHO. Table 1-4 lists major oceanographic survey vessels belonging to these agencies.

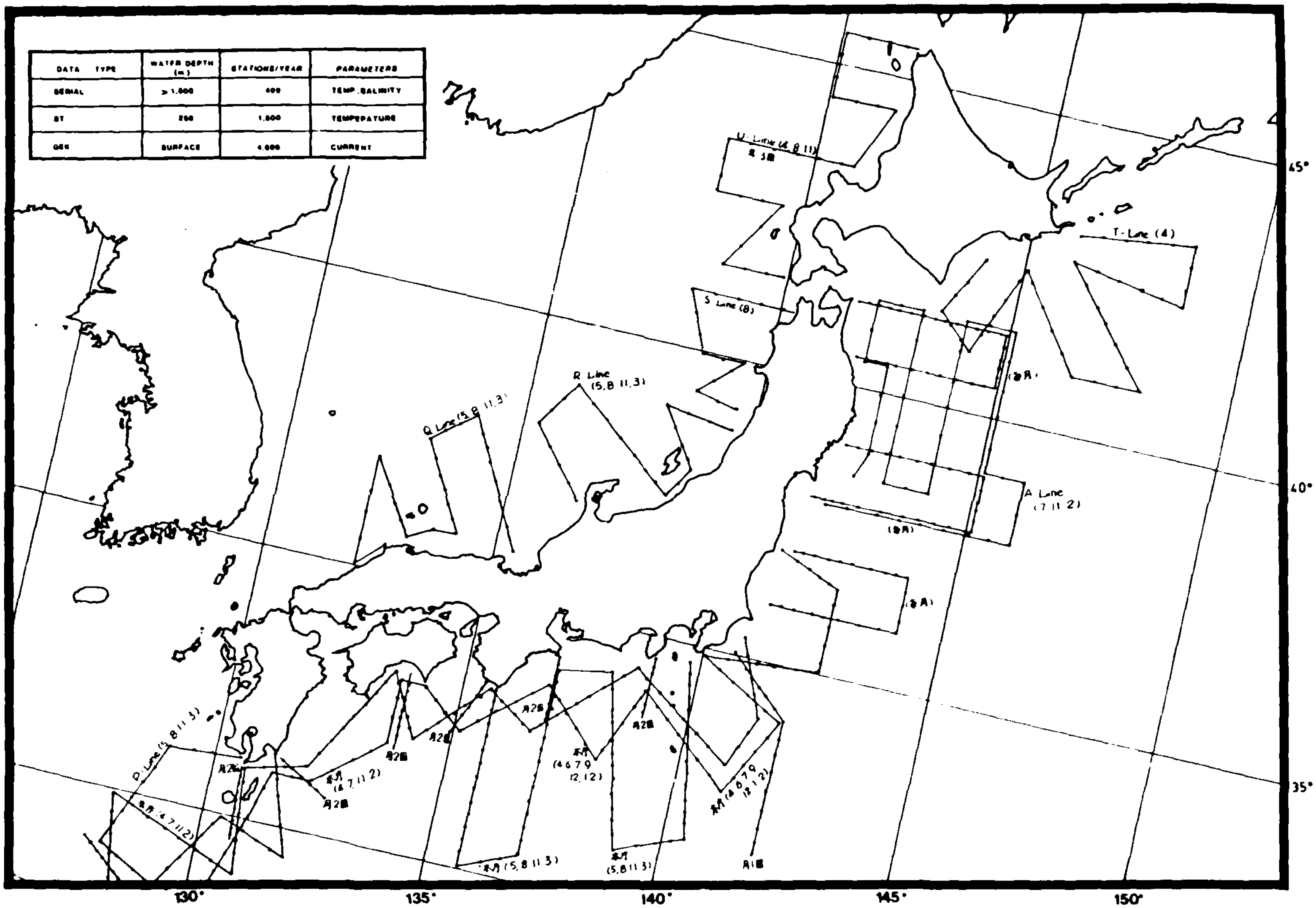
Table 1-5 compares the cumulative amount of serial observational stations which were occupied by various nations in the Pacific Ocean, on the basis of the data file at the Japan Oceanographic Data Center to October, 1973. This indicates that Japan accounted for more than a half (58%) of the data in the entire Pacific basin. The U.S.A., at 24%, was the second most data collecting nation in the region. Korea accounted for about 2%. Among the three governmnet agencies in Japan, the JHO ranked first with the JMA second and the JHO third.

The importance of the Japanese contribution in terms of serial observational data collection is even more dominant in the adjacent seas of Japan, as seen in Table 1-6. Here, Japan accounted for about 88% of the total; the U.S.S.R. ranked second with about 4% followed by the Republic of Korea with about 3%. The contribution by the U.S.A. in the adjacent seas of Japan was about 2.6%.

In terms of GEK measurements of ocean currents (see Table 1-7), approximately 6,000 measurements annually were taking place in recent years, with the JHO heading the list with about 50%, followed by the JMA with about 24% and the JFA with about 15%. The JHO, due to its strong interest in navigational safety, has traditionally stressed current measurements in its oceanographic data collection efforts.

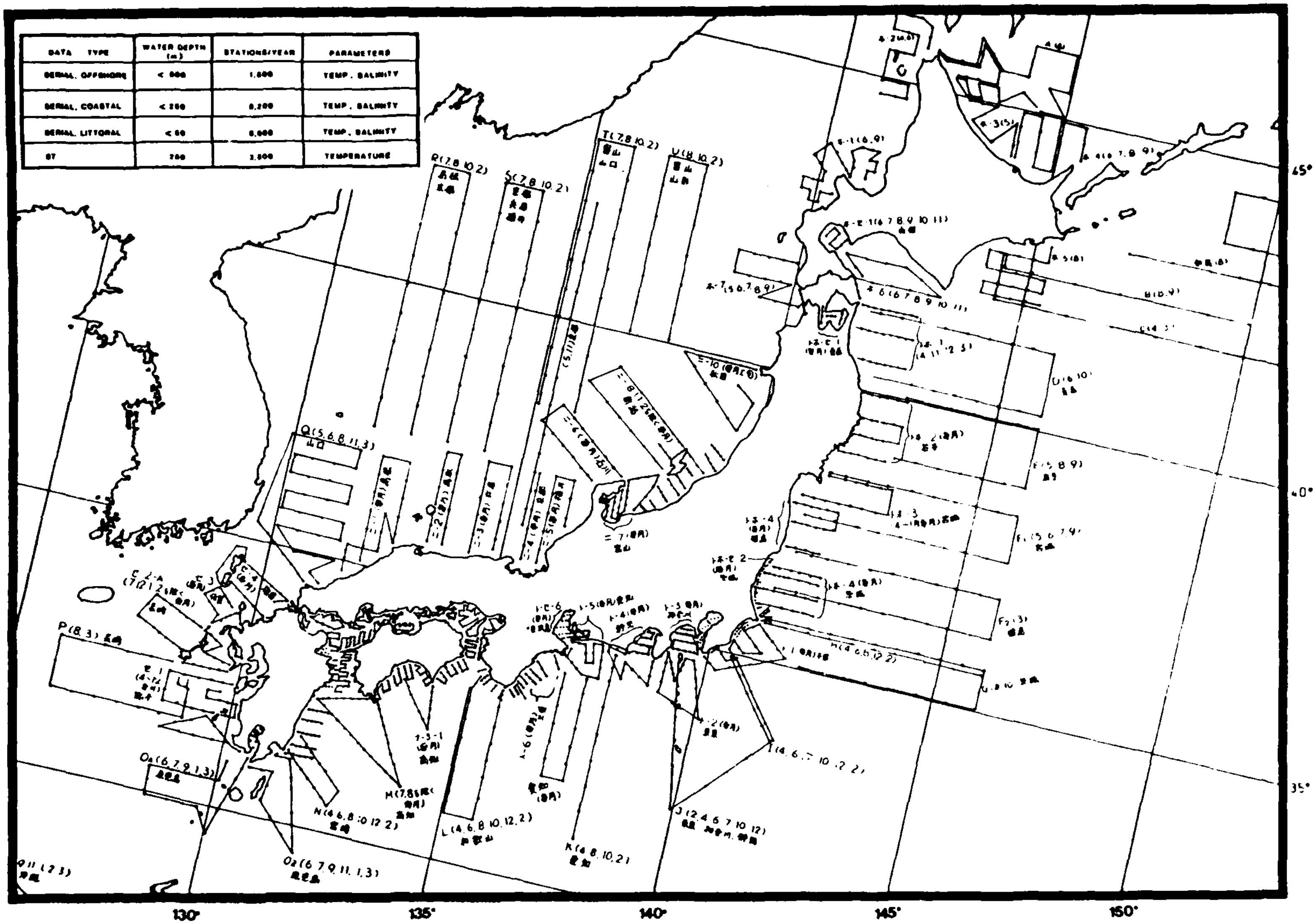
The JMA, on the other hand, is interested in a broad range of physical parameters. Whereas the serial observations by the JHO stressed mainly sea water temperature, salinity and currents, the JMA's data included additionally, D.O., nutrient salts such as Phosphate-P, Silicate-Si, Nitrate-N, and p.H., and marine weathers. The JFA's serial observations included plankton and fish samples in addition to temperature and salinity.

In Korea, the serial observational lines are divided into three groups consisting of the 100 series (102 through 107, in the Sea of Japan), the 200 series (203 through 209, in the southern sea) and the 300 series (306 through 314, in the Yellow Sea). While the Fisheries Research and Development Agency (FRDA) is in charge of the 100 and 200 series, respectively, in the Sea of Japan and the Yellow Sea, the Hydrographic Office is responsible for the 200 series which include the Tsushima Strait. Line 207, which is located astride the Tsushima Strait, is the oldest of all the serial lines, with its data dating back to 1922.



DATA TYPE	WATER DEPTH (m)	STATIONS/YEAR	PARAMETERS
SERIAL	> 1,000	400	TEMP, SALINITY
BT	200	1,000	TEMPERATURE
GEK	SURFACE	4,000	CURRENT

Figure 1-4. Typical cruise tracks for serial observations by Japan Hydrographic Office (JHO).



DATA TYPE	WATER DEPTH (m)	STATIONS/YEAR	PARAMETERS
SERIAL, OFFSHORE	< 500	1,800	TEMP., SALINITY
SERIAL, COASTAL	< 200	8,200	TEMP., SALINITY
SERIAL, LITTORAL	< 50	6,000	TEMP., SALINITY
BT	200	3,500	TEMPERATURE

Figure 1-5. Typical cruise tracks for serial observations by Japan Fisheries Agency (JFA) and its affiliated prefectural Fisheries Experiment Stations.

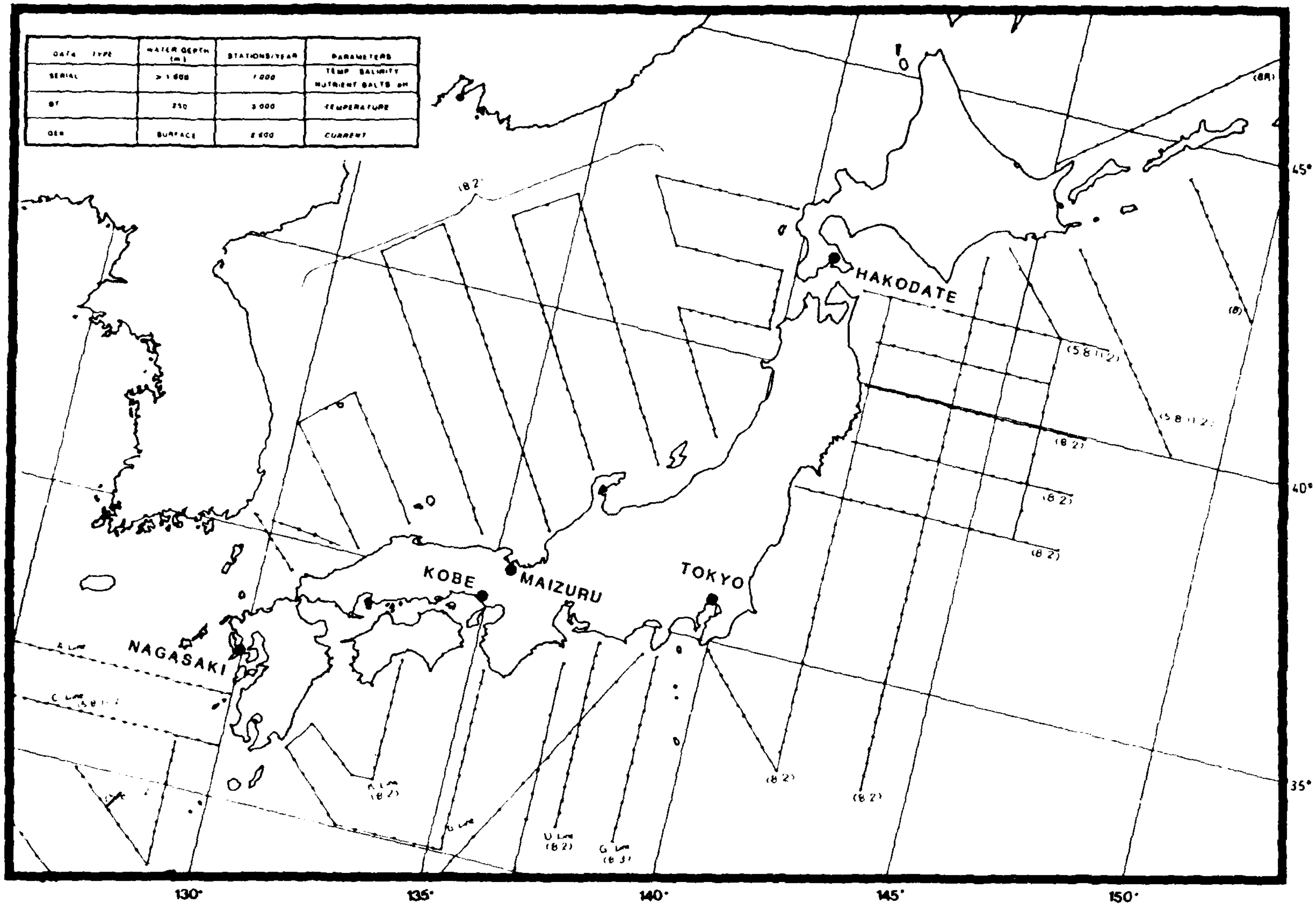


Figure 1-6. Typical cruise tracks for serial observations by Japan Meteorological Agency (JMA).

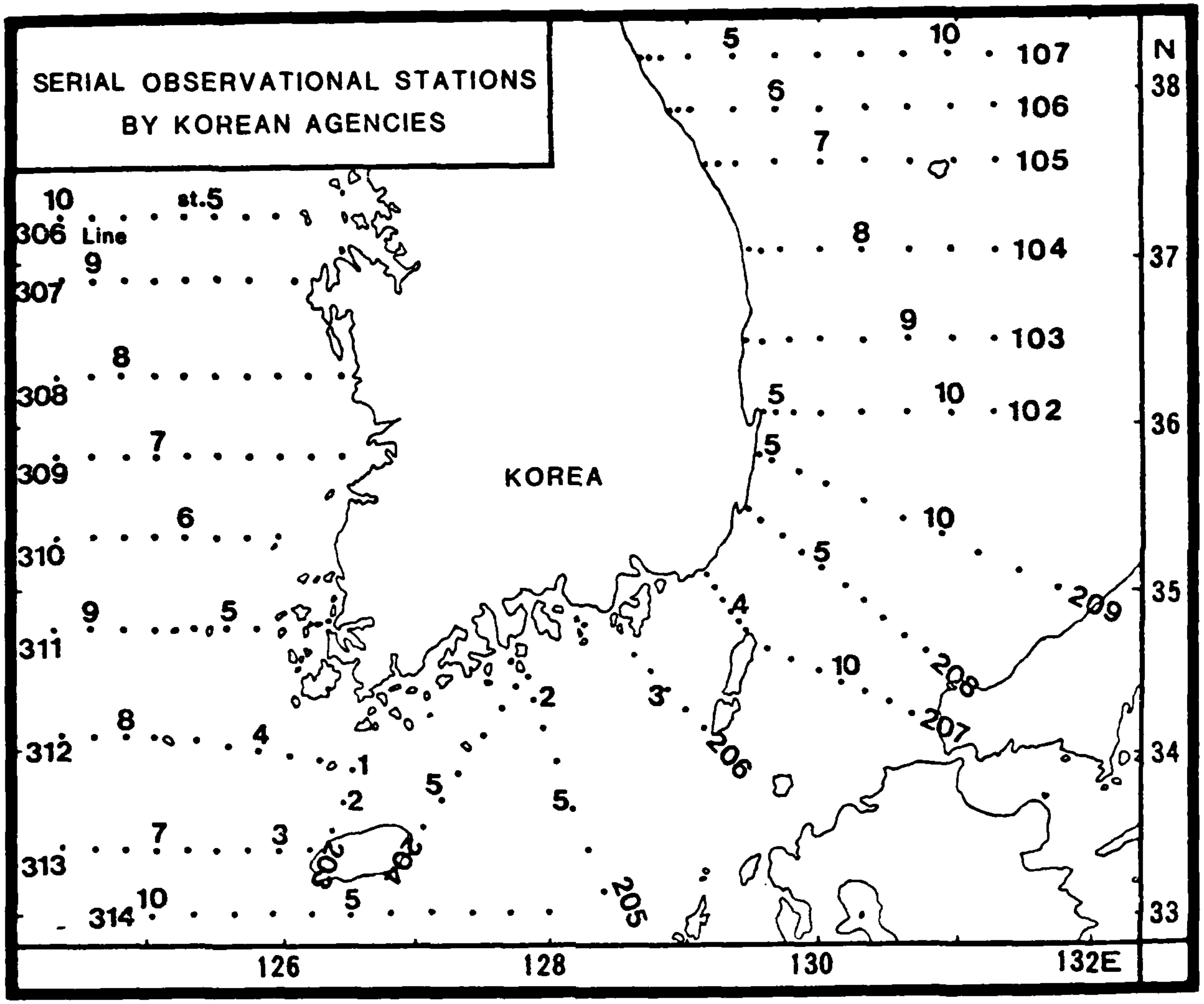


Figure 1-7. Fixed lines for serial observations by Fisheries Research and Development Agency and Hydrographic Office in Korea.

Line & Station	Location	Depth
306 - 02	37° 17' N, 126° 03' E	20m
03	37 17 125 50	20
04	37 17 125 38	20
05	37 17 125 25	34
06	37 17 125 13	40
07	37 17 125 00	50
08	37 17 125 47	63
09	37 17 124 35	65
10	37 17 124 22	71
307 - 03	36 56 126 00	37
04	36 56 125 38	29
05	36 56 125 25	45
06	36 56 125 12	55
07	36 56 125 00	60
08	36 56 124 47	70
09	36 56 124 35	78
10	36 56 124 22	80
308 - 01	36 19 126 13	12
02	36 19 126 02	20
03	36 19 125 50	39
04	36 19 125 37	50
05	36 19 125 25	52
06	36 19 125 13	57
07	36 19 125 00	68
08	36 19 124 48	76
09	36 19 124 35	83
10	36 19 124 23	80
309 - 01	35 51 126 14	15
02	35 51 126 01	28
03	35 51 125 49	40

Line & Station	Location	Depth
309 - 04	35° 51' N, 125° 37' E	56m
05	35 51 125 25	67
06	35 51 125 12	63
07	35 51 125 00	71
08	35 51 124 48	81
09	35 51 124 36	81
10	35 51 124 23	87
310 - 03	35 20 125 48	20
04	35 20 125 36	50
05	35 20 125 24	69
06	35 20 125 12	76
07	35 20 125 00	79
08	35 20 124 48	86
09	35 20 124 35	90
10	35 20 124 24	89
311 - 04	34 43 125 43	30
05	34 43 125 31	50
06	34 43 125 19	74
07	34 43 125 00	89
08	34 43 124 48	91
09	34 43 124 36	89
10	34 43 124 23	83
312 - 02	33 59 126 06	50
03	34 00 125 54	75
04	34 02 125 42	70
05	34 03 125 30	74
06	34 05 125 18	89
07	34 06 125 00	98
08	34 06 124 48	90
09	34 06 124 36	87
10	34 06 124 23	85

TABLE 1-3. List of fixed sectional serial stations around Korea.

Line & Station	Location	Depth
313 - 02	33° 24' N, 126° 00' E	83m
03	33 24 125 48	85
04	33 24 125 36	87
05	33 24 125 24	83
06	33 24 125 12	83
07	33 24 125 00	76
08	33 24 124 48	73
09	33 24 124 36	71
10	33 24 124 24	70
314 - 00	33 00 128 00	157
01	33 00 127 41	122
02	33 00 127 23	120
03	33 00 127 05	110
04	33 00 126 48	108
05	33 00 126 30	105
06	33 00 126 12	103
07	33 00 125 54	98
08	33 00 125 36	91
09	33 00 125 18	80
10	33 00 125 00	70
203 - 01	33 58 126 31	50
02	33 49 126 25	105
03	33 36 126 16	100
204 - 01	34 21 127 44	28
02	34 14 127 36	32
03	34 07 127 27	42
04	33 54 127 15	75
05	33 45 127 09	101
06	33 36 127 03	122

Line & Station	Location	Depth
205 - 01	34° 23' N, 127° 49' E	28m
02	34 15 127 53	40
03	34 06 127 57	60
04	33 52 128 03	85
05	33 38 128 09	106
06	33 24 128 15	130
07	33 10 128 21	170
08	33 00 128 27	205
206 - 01	34 35 128 38	50
02	34 30 128 41	75
03	34 23 128 50	90
04	34 15 128 58	130
05	34 08 129 06	110
207 - 01	35 01 129 07	83
02	34 58 129 11	101
03	34 54 129 15	115
04	34 50 129 20	225
05	34 48 129 22	158
06	34 44 129 26	74
07	34 39 129 37	92
08	34 34 129 48	107
09	34 29 129 58	120
10	34 24 130 09	106
11	34 19 130 19	113
12	34 14 130 30	96
13	34 09 130 40	80
208 - 01	35 28 129 27	70
02	35 24 129 33	130
03	35 18 129 44	153
04	35 11 129 53	153
05	35 05 130 02	140

TABLE 1-3. List of fixed sectional serial stations around Korea.
(Cont'd)

Line & Station	Location	Depth
208 - 06	34° 58' N, 130° 12' E	135m
07	34 52 130 21	130
08	34 46 130 31	130
09	34 39 130 41	130
10	34 33 130 50	116
209 - 04	35 47 129 33	64
05	35 45 129 39	80
06	35 41 129 50	300
07	35 37 130 01	350
08	35 31 130 17	250
09	35 24 130 34	160
10	35 18 130 51	140
11	35 11 131 07	130
12	35 05 131 23	125
13	35 59 131 39	120
102 - 04	36 05 129 37	52
05	36 05 129 42	210
06	36 05 129 48	700
07	36 05 130 00	1,390
08	36 05 130 19	1,530
09	36 05 130 37	1,480
10	36 05 130 55	1,640
11	36 05 131 14	1,500
12	36 05 131 32	1,200
13	36 05 131 51	1,200
103 - 04	36 30 129 30	110
05	36 30 129 35	200
06	36 30 129 48	600
07	36 30 130 00	1,050
08	36 30 130 19	2,050

Line & Station	Location	Depth
103 - 09	36° 30' N, 130° 37' E	2,000m
10	36 30 130 55	2,200
11	36 30 131 14	2,100
12	36 30 131 33	1,900
13	36 30 131 51	1,760
104 - 04	37 03 129 29	110
05	37 03 129 34	195
06	37 03 129 47	500
07	37 03 130 00	1,050
08	37 03 130 19	2,100
09	37 03 130 37	2,300
10	37 03 130 55	2,200
11	37 03 131 14	2,100
12	37 03 131 34	2,100
13	37 03 131 53	1,800
105 - 03	37 33 129 10	48
04	37 33 129 15	250
05	37 33 129 22	380
06	37 33 129 41	1,000
07	37 33 130 00	1,680
08	37 33 130 19	1,700
09	37 33 130 37	1,600
10	37 33 130 56	1,800
11	37 33 131 16	1,200
12	37 33 131 34	2,300
13	37 33 131 52	2,500
106 - 02	37 54 128 52	58
03	37 54 128 57	320
04	37 54 129 04	400
05	37 54 129 22	900
06	37 54 129 41	1,400

TABLE 1-3. List of fixed sectional serial stations around Korea. (Cont'd)

Line & Station	Location	Depth
106 - 07	37° 54' N, 130° 00' E	1,400m
08	37 54 130 19	2,200
09	37 54 130 38	1,000
10	37 54 130 56	1,500
11	37 54 131 15	1,000
12	37 54 131 35	1,500
13	37 54 131 53	2,200
107 - 01	38 13 128 39	45
02	38 13 128 43	500
03	38 13 128 51	900
04	38 13 129 04	1,100
05	38 13 129 23	1,300
06	38 13 129 41	1,450
07	38 13 130 00	1,700
08	38 13 130 19	2,000
09	38 13 130 38	2,150
10	38 13 130 56	1,700
11	38 13 131 16	1,300
12	38 13 131 34	1,400
13	38 13 131 54	1,300

TABLE 1-3. List of fixed sectional serial stations around Korea.
(Cont'd)

TABLE 1-4: Major oceanographic survey vessels associated with sea strait surveys.

AGENCY	SHIP	GROSS TON	L x B x D (m)	CREW	SCIENTISTS	DATE LAUNCHED
JAPAN HYDROGRAPHIC OFFICE (*)	Syoyo (or Shoyo)	1,900	80.0x12.3x6.5	42	24	2/26/1972
	Takuyo	771	62.4x 9.5x4.8	38	13	3/12/1967
	Myoyo	450	44.8x 8.0x3.8	22	13	3/15/1963
	Kaiyo	310	44.5x 8.0x3.8	20	7	3/14/1964
	Tenyo	121	30.2x 5.8x2.8	16	4	3/31/1961
JAPAN FISHERIES AGENCY(*)	Kaiyo Maru (M.)	2,539.5	91.9x15.0x9.2	60	16	9/23/1967
	Shoyo (or Syoyo) M.	1,377.8	72.0x11.0x5.6	41	7	3/21/1972
Hokkaido F.R.L.	Hokko Maru	1,377.8	72.0x11.0x5.6	25	6	6/30/1976
Hokkaido F.R.L.	Tankai Maru	102.2	26.0x 5.7x2.6	18	4	3/30/1964
Tohoku F.R.L.	Wakataka Maru	170.8	35.0x 6.0x3.1	18	4	3/25/1970
Tokai F.R.L.	So-o Maru	494.4	46.0x 9.3x4.6	25	6	3/25/1970
Seikai F.R.L.	Yoko Maru	499.8	49.0x 9.0x4.4	26	5	7/20/1979
JAPAN METEOROLOGICAL AGENCY (*)	Keifu Maru	1,795.8	81.7x12.6x6.5	35	18	12/16/1969
	Ryofu Maru	1,598.8	79.2x12.0x6.6	36	18	8/16/1966
Hakodate M.M.O.	Kofu Maru	345.9	47.0x 7.8x3.8	25	15	3/15/1973
Kobe M.M.O.	Shumpu Maru	373.1	48.5x 7.8x3.9	25	15	3/25/1974
Nagasaki M.M.O.	Chofu Maru	265.8	42.0x 7.4x3.8	23	18	8/ 1/1960
Maizuru M.M.O.	Seifu Maru	355.0	48.5x 7.8x3.8	26	15	3/17/1964
PREFECTURAL FISHERIES EXPERIMENT STATION (**)						
Kushiro F.E.S.	Hokushin Maru	219.5	36.0x 7.4x3.4	23	2	March/1968
Hakodate F.E.S.	Oyashio M.	237.2	36.0x 7.1x3.1	22	2	3/27/1969

(*): Ships over 100 Gross Ton only. (**): Stations related to sea strait survey only. (TO CONTINUE)

TABLE 1-4: Major oceanographic survey vessels associated with sea strait surveys. (Cont'd)

AGENCY	SHIP	GROSS TON	L x B x D (m)	CREW	SCIENTISTS	DATE LAUNCHED
PREFECTURAL FISHERIES EXPERIMENT STATION (**)						
Wakkanai F.E.S.	Hokuyo Maru	275.4	37.0x 8.2x5.3	25	3	8/28/1974
Aomori F.E.S.	To-o Maru	134.5	35.3x 6.5x2.9	17	2	6/23/197[illegible]
Nagasaki F.E.S.	Tsuru Maru	154.2	27.0x 6.5x2.8	14	4	8/15/1968
Saga F.E.S.	Kagami Maru	86.4	30.2x 5.5x2.5	8	7	7/22/1975
Fukuoka F.E.S.	Genkai Maru	85.0	24.8x 5.5x2.5	9	7	9/27/1967
Yamaguchi F.E.S.	Kuroshio Maru	149.3	35.2x 6.6x2.8	14	6	8/ 8/1975
Shimane F.E.S.	Shimane Maru	139.1	34.6x 6.5x2.8	12	5	11/29/1976
UNIVERSITIES						
Hokkaido Univ.	Hokusei Maru	892.9	62.3x11.1x4.6	27	44	10/30/1976
" "	Oshoro Maru	1,119.7	66.7x11.0x5.4	40	66	9/29/1962
Univ. of Tokyo Ocean Res. Inst.	Hakuho Maru	3,200.5	95.0x14.8x7.3	53	32	3/31/1967
" "	Tansei Maru	257.7	40.0x 7.4x3.7	23	11	6/20/1963
Tokyo Univ. of Fisheries	Umitaka Maru	1,828.7	79.0x12.4x6.0	35	67	6/22/1973
" "	Kamitaka Maru	382.1	47.0x 7.8x4.5	20	48	4/22/1963
" "	Aotaka Maru	210.8	33.8x 7.0x3.5	15	30	3/16/1966
Tokai Univ.	Bosei Maru, II	1,218.4	72.2x11.2x5.6	34	120	Oct./1978
" "	Tokai Daigaku Maru, II	702.6	50.6x 9.2x4.9	28	-	1/ 8/1968
Miye Univ.	Seikai Maru	359.3	47.0x 8.4x4.0	16	-	7/10/1980
Hiroshima Univ.	Hocho Maru	320.7	44.7x 8.3x4.0	12	19	9/20/1978

(**): Stations related to sea strait survey only.

(CONTINUED)

TABLE 1-4: Major oceanographic survey vessels associated with sea strait surveys.
(Cont'd)

AGENCY	SHIP	GROSS TON	L x B x D (m)	CREW	SCIENTISTS	DATE LAUNCHED
UNIVERSITIES						
Fisheries Univ. (Yamaguchi)	Koyo Maru	1,989.9	81.4x13.0x8.4	45	5	6/ 7/1978
" "	Ten-o Maru	518.3	48.0x 8.3x4.3	28	2	4/21/1964
Kagoshima Univ.	Kagoshima Maru	1,038.1	60.5x10.8x5.4	42	65	9/15/1960
" "	Keiten M.	854.6	57.0x11.0x6.9	31	38	7/5/1974
KOREA						
Fisheries Research Development Agency	Odaesan Ho	1,127	-	-	-	May, 1972
	Taebaeksan Ho	300	-	-	-	Mar.,1967
	Chirisan Ho	150	-	-	-	Mar.,1967
	Chunmasan Ho	84	-	-	-	Mar.,1967
	Hanrasan Ho	84	-	-	-	Mar.,1967
Hydrographic Office	No.5 Suro Ho	143	-	-	-	-
	No.6 Suro Ho	143	-	-	-	-
	No.7 Suro Ho	30	-	-	-	-
	No.8 Suro Ho	30	-	-	-	-
	No.9 Suro Ho	126	-	-	-	-
	No.10 Suro Ho	400	-	-	-	-
Ocean Research & Development Inst.	Banwol Ho	82	21 x 5.8x3.2	6	6	Sep.,1980

(CONTINUED)

TABLE 1-5

SUMMARY OF SERIAL OBSERVATIONAL STATIONS

BY COUNTRY IN THE PACIFIC OCEAN

CODE	COUNTRY	NUMBER OF STATIONS	OBSERVED YEAR
09	Australia	6,256	1938 - 68
18	Canada	7,790	1927 - 67
20	Chile	513	1948 - 68
24	Korea, Rep. of	3,566	1930, 1965-71
31	U.S.A.	40,760	1928 - 70
35	France	549	1949 - 69
42	Indonesia	528	1949 - 71
64	Netherlands	523	1929 - 30
65	Peru	2,017	1961 - 66
74	United Kingdom	1,043	1930 - 71
86	Thailand	1,195	1956 - 69
90	U.S.S.R.	5,223	1925 - 71
(*)	Others	2,340	–
	Sub-Total	72,299	
49	Japan		
	JHO	22,533	1923 - 73
	JMA	27,340	1947 - 72
	JFA	46,126	1933 - 71
	Univ.	3,703	1935 - 71
	Sub-Total	99,702	
	TOTAL	172,001	

SOURCE: JODC Serial Observational Data File to October, 1973

(*) All other countries with less than 500 total observed stations are grouped here, including Germany (24 stations), China (354), Colombia (151), Denmark (251), Ecuador (434), India (12), Mexico (50), Norway (1), New Caledonia (391), New Zealand (263), Philippines (196), Sweden (62), Yogoslavia (1), and Malaysia (150).

TABLE 1-6

SUMMARY OF SERIAL OCEANOGRAPHIC

OBSERVATIONAL STATIONS

(Adjacent Seas of Japan)

COUNTRY CODE	COUNTRY	NUMBER OF STATIONS	OBSERVED YEAR
06	Germany	19	1907
09	Australia	19	1964, 1967
21	China	354	1962-1963, 1965-1969
24	Korea	3,565	1930-1934, 1965-1971
26	Denmark	77	1929, 1951
31	U.S.A.	2,820	1929, 1946-1947, 1955-1970
35	France	44	1956, 1965, 1967
42	Indonesia	266	1949, 1956-1957, 1967, 1971
64	Netherlands	158	1929-1930
66	Philippines	199	1968-1969
74	United Kingdom	610	1951-1952, 1965-1971
77	Sweden	3	1948
86	Thailand	1,109	1956-1957, 1967-1969
90	U.S.S.R.	3,774	1925-1927, 1957-1962, 1965-1970
95	Yugoslavia	1	1959
	Sub-total	13,018	
49	Japan		
	JHO	21,342	1923-1924, 1927-1943, 1946-1972
	JMA	26,301	1947-1972
	JFA	44,343	1933-1944, 1947-1953, 1956, 1961 1963-1966, 1968, 1970-1971
	UNIV.	1,553	1935-1939, 1954, 1956-1971
	Sub-total	93,539	
	TOTAL	106,557	

DATA SOURCE: JODC, TO OCT. 1973

TABLE 1-7: Summary of GEK STATIONS
(Adjacent Seas of Japan)

NUMBER OF STATIONS

OBSERVED YEAR	JAPAN					U.S.S.R.	TOTAL
	JHO	JMA	JFA	DA	UNIV	NHS	
1953	86	0	0	0	0	0	86
1954	952	0	0	0	0	0	952
1955	1,851	74	0	0	0	0	1,925
1956	2,839	797	0	0	0	0	3,636
1957	2,620	1,434	0	0	4	0	4,058
1958	3,420	1,196	0	0	31	0	4,647
1959	2,908	1,136	0	0	0	0	4,044
1960	3,654	1,363	0	0	0	0	5,017
1961	3,317	1,516	0	0	0	0	4,833
1962	2,924	1,300	0	0	0	0	4,224
1963	2,910	1,505	0	0	0	0	4,415
1964	3,038	1,566	820	0	0	0	5,424
1965	3,222	1,694	563	0	31	0	5,510
1966	3,408	1,717	598	0	85	0	5,868
1967	2,976	1,764	753	0	158	0	5,651
1968	3,126	1,057	704	0	140	123	5,150
1969	3,232	1,427	633	0	15	17	5,324
1970	3,056	1,726	731	95	58	0	5,666
1971	3,368	1,666	1,256	40	52	0	6,382
1972	3,205	1,519	1,244	34	139	0	6,141
1973	3,888	1,429	897	88	171	0	6,473
1974	3,311	1,174	612	482	241	0	5,820
1975	3,374	1,312	943	360	178	0	6,167
1976	3,361	1,253	986	574	172	0	6,346
1977	3,017	1,464	927	661	0	0	6,069
TOTAL	73,123	31,089	11,667	2,334	1,475	140	119,828

DATA SOURCE: JODC GEK FILE, 1955-1977

Serial data observations by the universities are oriented toward specific research objectives at the time of cruise, and their locations are variable from time to time. The universities do not routinely participate in a coordinate cruise schedule of the government agencies, and the number of stations they occupy is quite limited.

Japanese oceanographic data are known for high degree of accuracy. As early as 1936, a detailed instruction manual on oceanographic data acquisition "Kaiyo Kansoku-ho" (Methods in Oceanographic Observations) was published by the Imperial Marine Observatory at Kobe. The manual was revised in 1955 as "Kaiyo Kansoku Shishin" (Guidelines for Oceanographic Observations) under the sponsorship of the Japan Oceanographical Society, and again in 1970.

While the determination of salinity and chlorinity prior to 1960 was carried out by means of the Nansen bottle, use of salinometer has spread rapidly among the data collectors since 1960 when Umitaka Maru of the Tokyo University of Fisheries employed the instrument for the first time on her cruise to the Indian Ocean. Today, an STD and BT are standard equipment of the survey ships of all the major data collectors in Japan. Accuracy of oceanographic data taken by Korean oceanographers improved by leaps and bounds since mid-1960 when they commenced active international cooperation with the CSK program.

1.4 Tide and Tidal Currents

As already shown in Table 1-1, tide measurements are the responsibility being shared by various agencies dedicated to different institutional objectives in Japan and Korea. In Japan, as of 1980, there were a total of 179 standard tide stations, of which 56 stations belonged to the JMA, 49 to the Ports and Harbors Bureau, 25 each to the JHO and the Geographical Institute, 22 to the Hokkaido Development Agency, and 2 to the Okinawa Development Agency. Most (64%) of the JMA tide stations were capable of telemetry data transmission, whereas none of the JHO stations had this capability.

Figure 1-8 summarizes the tide stations adjacent to the sea straits in Japan.

On the other hand, measurement of tidal currents is primarily the responsibility of the Hydrographic Office in Japan, whereas some measurements are also conducted by the Ports and Harbors Bureau, the Hokkaido and Okinawa Development Agencies (see Figure 1-9(A),(B)). Of the three sea straits which are of interest to this study, tidal currents have been most intensely measured and studied in the East Channel of the Tsushima Strait and its vicinity by the Japanese agencies; measurements at the Tsugaru Strait have been relatively sparse; and there has been relatively few measurements close to the Soya Strait.

Table 1-8 summarizes historical tidal current measurements adjacent to sea straits by the JHO and other government agencies in Japan.

In Korea, a total of 16 primary tide stations are maintained by the Korea Hydrographic Office. Figure 1-10 shows their locations. Table 1-9 shows the locations and the duration of the primary tide observations of these stations. Data being collected includes hourly heights, times and heights of daily high and low waters, and daily mean sea level. Daily mean sea level and highest and lowest heights for each month at selected stations are published annually in the Technical Reports of the KHO. Additionally, short-term tide observations have been conducted at secondary stations for the purpose of obtaining M2, S2, O1 and K1 constituents. Since 1955, more than 100 secondary stations have been occupied by the KHO.

Tidal current measurements were carried out by the KHO at about 20 locations between 1955 and 1980, the results being published in the Technical Reports. Table 1-10 summarizes the historical tidal current measurements by the Korea Hydrographic Office.

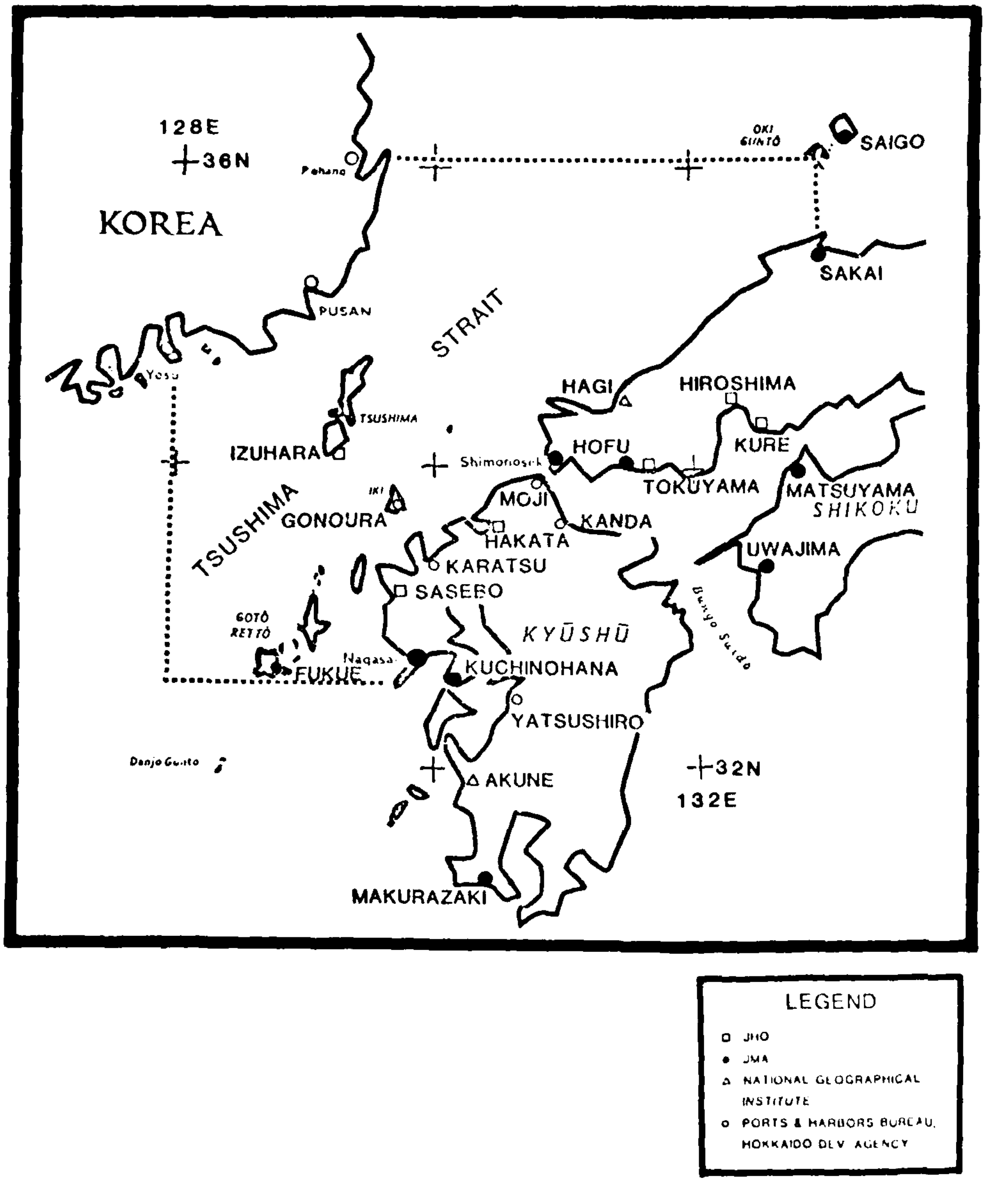


Figure 1-8(A). Tide stations on sea straits.

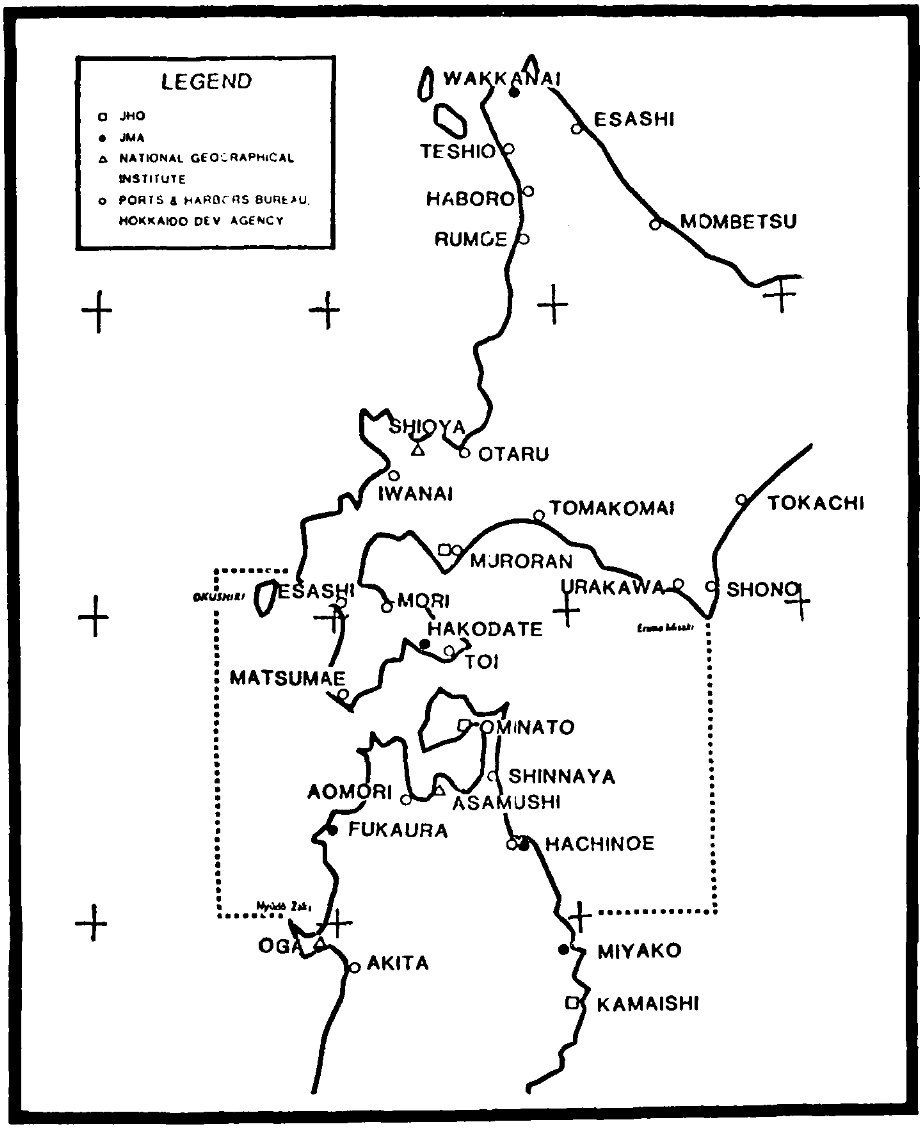


Figure 1-8(B). Tide stations adjacent to Tsugaru and Soya Strait.

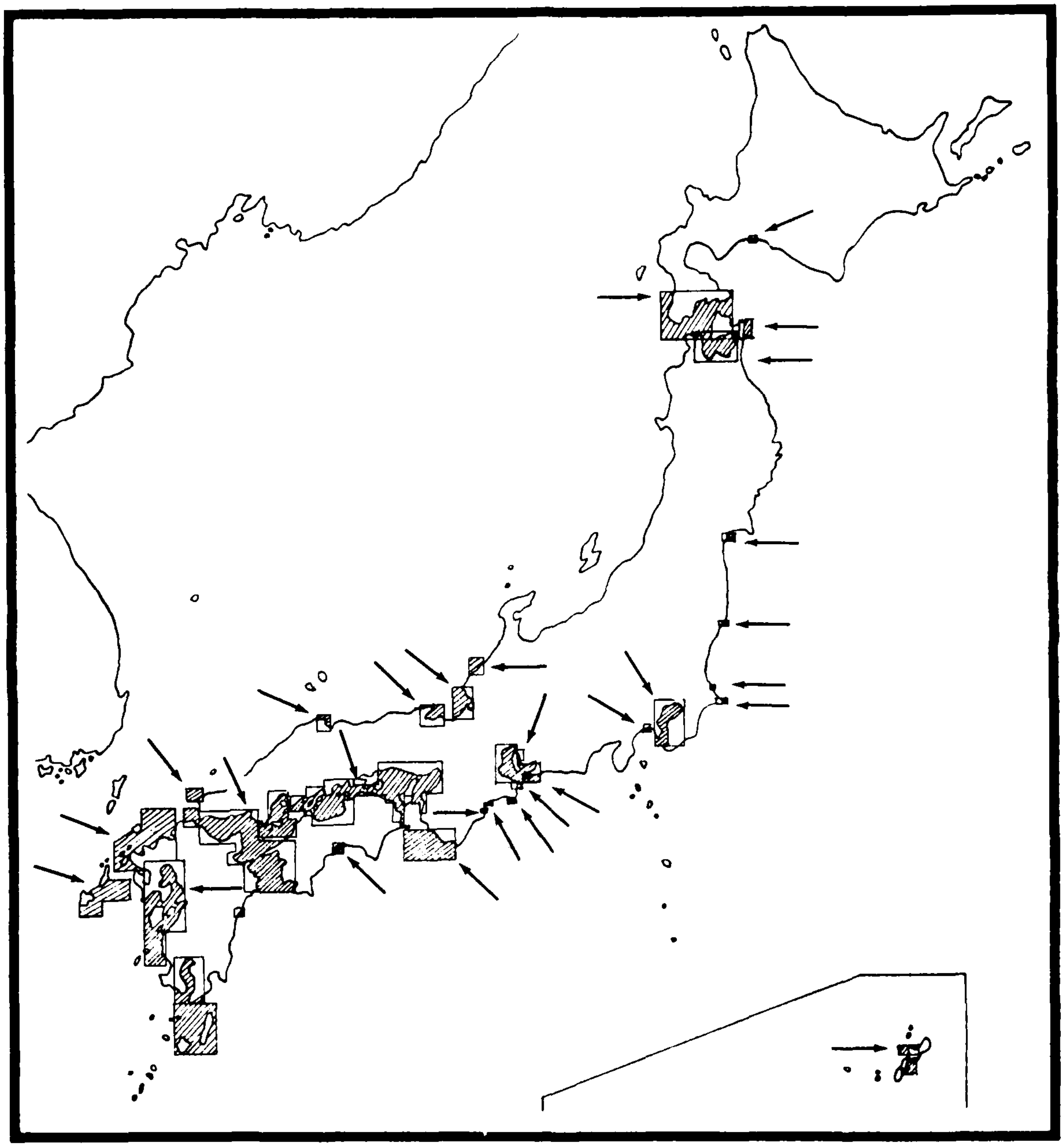


Figure 1-9(A). Tidal current stations by JHO.

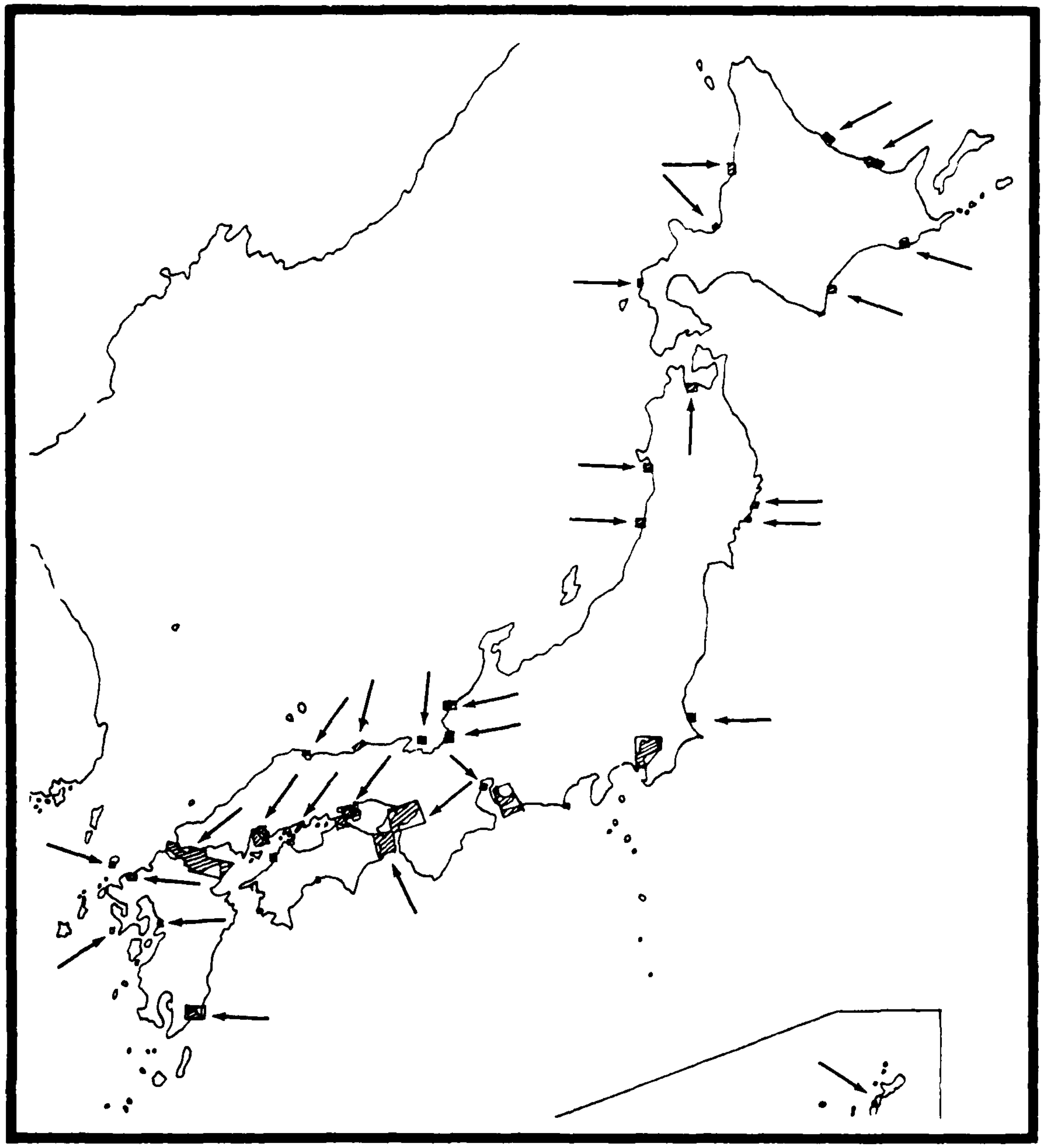


Figure 1-9(B). Tidal current stations by non-oceanographic services.

AREA	RELEVANT SEA STRAIT	SURVEY YEAR	DEPTH BELOW SURFACE (m.)	DATA POINTS	PUBLICATION
Karatsu Bay	Tsushima (upstream of East Channel)	1979	5	32	JHO Chart
Karatsu Harbor	"	1976	1.5 (1.5 above bed)	9	PHB File
Imari Bay	"	1976	5	25	Hydrographic Bull. #99
Northern Kyushu	"	1972	3	26	JHO Chart
Fukuoka Bay	"	1966	3	28	JHO Chart
Iki Channel	Tsushima, East Channel	1964	3	33	JHO Chart
Genkai Nada	"	1961	3	24	JHO Chart
Nagasaki Harbor	Tsushima (upstream)	1975	5	25	Hydrographic Bull. #98
Hario Seto	"	1951-74	3	21	Hydrographic Bull. #97
Sasebo Harbor	"	1965	3	21	JHO Chart
Hirato Seto	"	1948	2	36	Hydrographic Bull. #14
Goto Nada	"	1969	10	13	JHO Chart
Kakushima	Tsushima, East Channel	1978	3-5	30	JHO Chart
Tsugaru Strait	Tsugaru	1975-77	10	47	JHO Chart
Mutsu Bay	"	1968-70	5	76	JHO Chart
East of Shimo-Kita Peninsula	"	1962	5	5	JHO Chart
Aomori	"	1979	0.5, 2.0, 10.0	1	PHB File
Setana	Tsugaru (NW of Hokkaido)	1975	(1m above bed)	2	HDA File
Ishikari Bay	"	1976-77	0.5 (1m above bed)	12	HDA File

TABLE 1-8. Summary of historical tidal current measurements adjacent to sea straits in Japan.

AREA	RELEVANT SEA STRAIT	SURVEY YEAR	DEPTH BELOW SURFACE (m.)	DATA POINTS	PUBLICATION
Ishikari Bay	Tsugaru (NW of Hokkaido)	1979	1 (1m above bed)	5	HDA File
Rumoe Harbor	"	1978	2 (1m above bed)	16	HDA File
Rumoe Harbor	"	1979	2 (2m above bed)	5	HDA File
Mombetsu Harbor	Soya (downstream)	1977	1 (1m above bed)	4	HDA File
Mombetsu Harbor	"	1978	"	12	HDA File
Mombetsu Harbor	"	1979	"	2	"
Notori Harbor	"	1976	1 (1-2 above bed)	15	"
Abashiri Harbor	"	1976-77	1 (2m above bed)	20	"
Notori Harbor	"	1977	0.5 ~ 1m (and mid layer)	8	"

JHO: Japan Hydrographic Office
PHB: Ports and Harbors Bureau
HDA: Hokkaido Development Agency

TABLE 1-8. (Cont'd) Summary of historical tidal current measurements adjacent to sea straits in Japan.

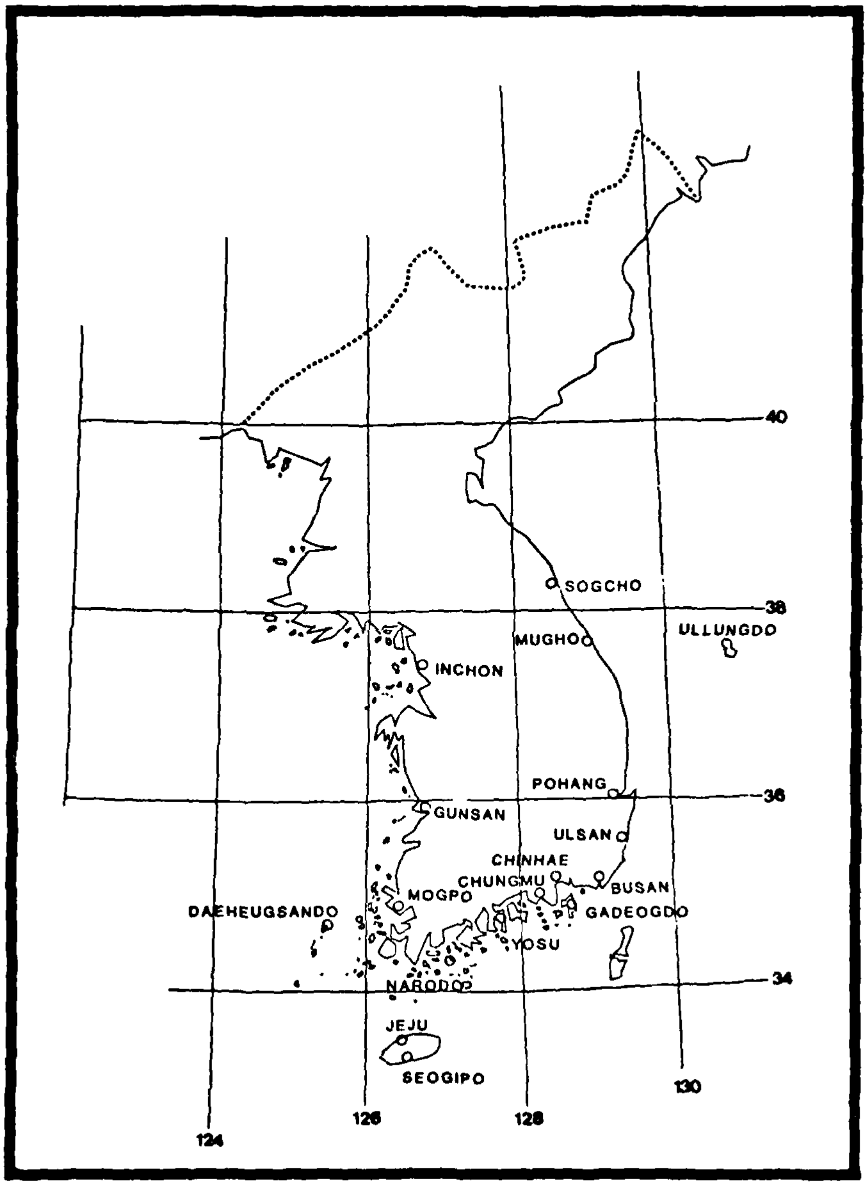


Figure 1-10. Primary tide stations under Hydrographic Office in Korea.

TABLE 1-9. Summary of primary tide stations under Korea Hydrographic Office.

PRIMARY STATION	LATITUDE	LONGITUDE	START DATE
SOGCHO*	38°12'15"N	128°35'47"E	1.11.1973
ULLUNGDO	37 29 36	130 54 50	17. 8.1965
MUGHO*	37 32 51	129 07 07	1. 1.1966
POHANG*	36 01 04	129 23 57	1. 2.1971
ULSAN*	35 30 44	129 23 13	1. 1.1965
BUSAN*	35 05 35	129 02 15	1. 1.1961
CHINHAE	35 08 36	128 38 48	1. 1.1960
GADEOGDO	35 01 18	128 48 47	1.12.1976
CHUNGMU*	34 49 28.5	128 48 47	31. 1.1976
YOSU*	34 44 39	127 46 05	1. 1.1966
JEJU*	33 33 51	126 31 50	1. 1.1964
SEOGIPO	33 14 12	126 33 51	11.12.1979
DAEHEUGSANDO	34 41 05	125 26 45	1. 1.1970
MOGPO*	34 46 41	126 23 33	1. 1.1960
GUNSAN	35 59 25	126 42 46	1. 1.1972
GUNSAN (Outer Harbor)	35 58 06	126 39 36	6. 2.1980
INCHEON*	37 28 08	126 35 51	1. 1.1963

(*) Daily and monthly mean sea levels as well as monthly highest and lowest heights of each year are given in the Technical Report of Korea Hydrographic Office for respective years from 1962. Source: Suk-Woo Lee (Personal communication, 1981)

TABLE 1-10. Summary of tidal current measurements by Korea Hydrographic Office.

AREA	LONGITUDE	LATITUDE	PERIOD	TECHN. REPORT	AUTHOR
NARODO	34°04'N	127°04'E	4-9,1978	1978	
YEOSU	34 20	127 34	4-10,1977	1977	
INCHEON	37 30	126 35	7-8,1977	1977	
CHEUNGMU	34 44	128 00	8-9,1976	1976	
BUSAN	35 05	129 07	1955-1960	1975	S.M. Hong
GADEOGSUDO	34 58	128 33	5-6,1975	1975	D.S. Kim
YEONGIL BAY	36 01	128 26	1971-1973	1973	D.G. Oh
GEOGNEOLBI-YEOLDO	37 00	126 10	5-7,1973	1973	D.G. Oh
ASAN BAY	37 24	126 34	4-9,1972	1972	Y.C. Gang
JANGJUGSUDO	34 23	125 58	5-8,1971	1971	Y.C. Gang
HOENGGAN SUDO	34 26	126 49	8-12,1970	1970	Y.C. Gang
YEONPEONGDO	37 18	126 18	5-9,1969	1969	Y.C. Gang
YEOSU	34 43	127 46	5-8,1968	1968	S.M. Kim
YEOSU BAY	34 50	127 47	6,1967	1967	Y.C. Gang
SAMCHEONPO	34 55	128 00	9-12,1967	1967	S.M. Kim
GUNSAN	35 59	126 43	5-6,1966	1966	S.M. Kim
YIDO	36 04	126 30	5-6,1966	1966	Y.C. Gang
HUGSANDO	34 55	125 37	5-6,1965	1965	S.M. Hong
MOGPO	34 55	126 18	4-6,1965	1965	S.W. Lee
PUSAN INCHEON	37 18	126 27	1952-1960	1962	S.W. Lee

Data on mean sea level and chart datum in Japan is handled by the Japan Hydrographic Office. The data is reviewed and updated every three years and published as JHO Pub. No. 741, titled:

"List of Mean Sea Levels and Chart Datums".

The latest edition was dated June, 1980. The mean sea level is an average of hourly tide records. The chart datum is determined by subtracting the sum of the amplitudes for M2, S2, K1 and O1 tides from the mean sea level.

Usually, tide stations are tied to a first class bench mark of the nationwide network, but because of frequent seismic disturbances and the unstable earth crust in Japan, a serious difficulty is encountered when one attempts to compare mean sea levels at points far apart from each other. The leveling of the network of the first class bench marks has been carried out several times since the beginning of the century, but the surveys were sporadic and piecemeal, so that the exact relationship between distant locations has not been assured. The latest effort of leveling took place between 1963 and 1968, a reasonably short period of time, and covered much of the country except for some substantial portion of northern and eastern Hokkaido. Included in this leveling were the coasts facing the Tsushima Strait and those facing the Tsugaru Strait both on Honshu and Hokkaido. A large region adjacent to the Soya Strait was left out in this survey. The leveling data was published in 1969 by the Geographical Institute.

1.5 Published Data Sources

There exist numerous data reports being published by various central and local government agencies at various time intervals, plus reports from academic and research institutions both in Japan and Korea. According to a recent tally by Japan Oceanographic Data Center, about 20,000 oceanographic stations, 15,000 MBT and 8,000 current (GEK) data annually are being taken in Japan alone.

Table 1-11 shows the principal data sources which were used in this study. Whereas all the sources named in Table 1-11 have been reviewed for this study, most important of these data sources are the annual data reports of serial observations being issued by government agencies as follows:

Japan Hydrographic Office (JHO):

"Data Report of Hydrographic Observations"

This report combines all the serial oceanographic and tide data taken by the 11 regional Hydrographic Office branches and a network of tide stations, including all the data which has already appeared in the prompt reports from the regional branches. A chronology of this publication and its predecessors is listed in Table 1-12.

"Guide to CSK Data" (1978)

This report, compiled by the Kuroshio Data Center (KDC)/ Japan Oceanographic Data Center (JODC), gives a comprehensive data inventory of the CSK (Cooperative Study of the Kuroshio) data during a period between 1965 and 1977. It contains a complete tally of data acquisition activities and ship tracks for all the CSK cruises.

Japan Fisheries Agency (JFA):

"Results of Fisheries Oceanographic Observations"

This report summarizes all the annual data collected by JFA's 8 regional Fisheries Research Laboratories, plus the data collected by all the prefectural, municipal and local Fisheries Experiment Stations. A chronology of this report is listed in Table 1-13.

Japan Meteorological Agency (JMA):

"Results of Marine Meteorological and Oceanographical Observations"

This report summarizes all the data taken by JMA's 4 regional Marine Meteorological Observatories (Kobe, Hakodate, Nagasaki, and Maizuru), and supercedes all the regional Data Reports and Prompt Reports. A chronology of this publication is listed in Table 1-14.

Korean Fisheries Research and Development Agency (FRDA):

"Annual Report of Oceanographic Observations"

This report summarizes all the data taken jointly by the Korean Fisheries Research and Development Agency and the Korean Hydrographic Office (KHO) along the fixed sectional survey lines which are being occupied bimonthly. Its predecessor is "Annual Report of Hydrographic Observations" (1954 - 63), the data quality of which appears to be somewhat inferior. A chronology of this report is listed in Table 1-15.

Korea Hydrographic Office (KHO):

"Technical Reports"

This report contains serial data obtained by KHO along the 200-series lines.

The following two agencies have compiled comprehensive atlases of oceanographic data:

Japan Oceanographic Data Center (JODC):

"Marine Environmental Atlas: Northwestern Pacific Ocean I," (1975).

This atlas presents statistical means, maximum and minimum values, and standard deviations of the serial observation data over a period of almost 70 years between the early 1900's and 1971, totaling approximately 110,000 data points.

"Marine Environmental Atlas: Northwestern Pacific Ocean II," (1978).

This atlas gives a finer breakdown of geographical areas on monthly and seasonal basis. Detailed presentation for

the Adjacent Seas of Japan (120° - 150°E, 24° - 46.5°N) and monthly statistics for selected 1-degree square areas (including Tsushima, Tsugaru and Soya Straits) proved particularly useful for this study.

"Marine Environmental Atlas: Currents - Adjacent Seas of Japan" (1979).

This atlas compiles a total of approximately 110,000 GEK data points between 1953 and 1977 into a series of statistical values by the whole period and by seasons.

Korea Ocean Research and Development Institute (KORDI):

"Oceanographic Atlas of Korean Waters, Vol. 1: Temperature Structure.

This report provides comprehensive plottings of temperature data on the basis of the sectional surveys which mainly took place between 1961 and 1975, and some dating back to 1922. It gives a particularly detailed presentation of data along Lines 207 and 208 which traverse the Tsushima Strait West Channel and a downstream area, respectively.

Additionally, for the purpose of assisting in this study, the JODC has kindly provided computer runs on its data base to prepare vertical summary statistics of temperature and salinity at a 1-degree resolution and GEK statistics at 15-minute resolution for the most part of the Adjacent Seas of Japan including the three sea straits under study for this report.

Although the subjects of marine sediment and marine geology are outside the scope of the present study, the extent of existing data sources is outlined as follows:

Principal agencies in Japan with active interest in marine sediment and geology are: Japan Hydrographic Office, Japan Geological Survey, Geographical Institute, and universities (particularly Ocean Research Institute of the University of Tokyo). Of these agencies, the interest of the Geographical Institute is limited to the coastal and nearshore zones.

The Japan Hydrographic Office publishes three map series relating to marine sediment and geology, plus special publications containing in-depth studies. A complete list of these publications is available in:

"Catalogue of Charts and Publications", JHO Pub. No. 900, revised October, 1979.

The map series consist of the following publications:

"Basic Maps of the Sea in Continental Shelf Areas"
(scale 1: 200,000):

1. Bathymetric charts
2. Submarine structural charts
3. Total magnetic intensity charts
4. Gravity anomaly charts

Of a total of 77 basic maps of this series planned around Japan, 54 were completed and published between 1970 and 1979. The published maps cover all the three sea straits under study in this report.

"Basic Maps of the Sea in Coastal Waters"
(scale 1: 50,000)

These maps consist of bathymetric charts and submarine structural charts with greater emphasis on local details than the continental shelf series. Most of the surveys for these maps were initiated since 1971, and approximately 50% of the work was completed for publication by 1979.

"Basic Maps of the Sea"
(scale 1: 3,000,000)

Bathymetric charts showing the entire Adjacent Seas of Japan in a set of four maps.

Of the various special publications by the JHO, those which are relevant to the sea straits under study in this report are the following two volumes:

Nagano, M., M. Sakurai, M. Uchida, K. Ikeda, H. Taguchi and T. Omori, 1974. Submarine Geology off Northeast Coast of Hokkaido District. Report of Hydrographic Researches, JHO, No. 9, 31 p. (Japanese with English abstract; out of print).

Sakurai, M., M. Nagano, T. Nagai, T. Katsura, M. Tozawa, and K. Ikeda, 1975. Submarine Geology off the South Coast of Hokkaido. Report of Hydrographic Researches, JHO, No. 10, 37 p. (Japanese with English abstract; out of print).

Various articles relating to marine sediment, sand waves and marine geology appear in the JHO Hydrographic Bulletin from time to time.

Any inquiries relating to the JHO data on marine sediment and

geology may be directed to:

Dr. Akio Mogi
Director, Ocean Survey Section
Japan Hydrographic Office
Maritime Safety Agency
3-1, 5-Chome, Tsukiji
Chuo-Ku, Tokyo 104
Japan

The Japan Geological Survey has two publication series which deal with marine geology: Marine Geological Map Series and Cruise Reports.

"Marine Geology Map Series"

As of 1981, a total of 15 sets of this series have been published, of which 9 sets are in scale 1: 200,000 and 6 in scale 1: 1,000,000. Each set generally consists of different combinations of maps displaying surface sediment types, textures, composition of coarse fraction (0.5 mm), mud content, grain size histograms, phi median values, sorting coefficients, bottom features, geological structures, magnetic anomalies, free-air gravity anomalies, Bouguer gravity anomalies, etc.

"Cruise Reports"

The Japan Geological Survey embarked on a 5-year program in 1974 aiming to investigate mineral sources on the sea floor surround Japan and in the distant seas. As of 1981, a total of 15 cruise reports have been published with two more in press. The cruises, conducted by the the Survey's Hakurei Maru, generally carry out the following surveys:

Geophysical Methods:

- Bathymetric survey by 12 kHz PDR
- Subbottom profiling by 3.5 kHz PDR
- Continuous seismic profiling by air gun and sparker
- Refraction measurements by sono-radio buoy
- Magnetic survey by proton magnetometer
- Gravity measurements by on-board gravimeter
- Surficial current measurement by GEK

Geological Methods:

- Bottom sampling by chain-bag and cylinder dredges
- Bottom sampling by rock corer
- Bottom sampling by piston corer with 6 m core barrel

Among the published cruise reports relevant to the sea straits under study in this report are:

Cruise Report No. 2: Geological Investigation of Goto Nada and Tsushima Strait, 1972-73.

Cruise Report No. 6: Geological Investigation of Ryukyu Island (Nansei Shoto) Arc, 1975.

Cruise Report No.10: Geological Investigation of the Northern Margin of the Okinawa Trough and the Western Margin of the Japan Sea, 1977.

Cruise Report No.11: Geological Investigation of the Okhotsk and Japan Seas off Hokkaido, 1977.

Cruise Report No.13: Geological Investigation of the Japan Sea, 1978.

Any further inquiries regarding the sediment and geological data by the Japan Geological Survey may be directed to:

Dr. Atsuyuki Mizuno
Director, Marine Geology Department
Japan Geological Survey
1-1-3 Higashi, Yatabe, Ibaraki 305
Japan

The University of Tokyo's Ocean Research Institute, founded in 1962, serves as a joint research arm for oceanographic departments of various universities in Japan. The Institute operates two survey/research ships: Taisei Maru (257 GT) and Hakuho Maru (3,200 GT). The Institute has three research departments dealing with the ocean floor: Geophysics, Marine Sediment, and Tectonics Departments. Whereas the researchers publish their papers in the journals of individual choice, the Institute publishes its own bulletin (unscheduled) and preliminary cruise reports. Any inquiries may be addressed to:

Dr. Noriyuki Nasu
Director
Ocean Research Institute
University of Tokyo
15-1, 1-Chome, Minami-Dai
Nakano-Ku, Tokyo 164
Japan

HEAD AGENCY	DATA REPORTS	DATA TYPE						YEARS/ PUBLICATION
		SERIAL SURVEYS	MBT	XBT	GEK	TIDE	TIDAL CURRENT	
JHO	Hydrograph c Bulletin (Navy Hydrographic Office)	*						1926-41
	Oceanographic Bulletin	*				*	*	1947-49
	Hydrographic Bulletin	*				*	*	1947-80
	Data Report of Hydrographic Observations, Series of Oceanography	*	*	*	*			1965-80
	Data Report of Hydrographic Observations, Series of Tide					*	*	1965-80
	Oceanographic Prompt Reports *(Various Regional Offices)*	*	*	*	*	*	*	c. 1950-80
	Tide Table							Annual
	List of Mean Sea Levels and Chart Datums					*		Occasional
	Japan Oceanographic Data Center: Marine Environmental Atlas:							
	Northwestern Pacific Ocean I		*	*	*			1977
	Northwestern Pacific Ocean II		*	*	*			1978

TABLE 1-11. Principal sources of published oceanographic data.

(Continued)

HEAD AGENCY	DATA REPORTS	DATA TYPE						YEARS/ PUBLICATION
		SERIAL SURVEYS	MBT	XBT	GEK	TIDE	TIDAL CURRENT	
	Currents-Adjacent Seas of Japan				*		*	1979
	Oceanographic Data Report of CSK							1966-69
	Data Report of CSK	*	*	*	*			1966-78
	Guide to CSK Data	*	*	*	*			1981
JFA	Oceanographic Investigation *(Imperial Fisheries Institute)*	*						1911-34
	Fishery Investigation *(Imperial Fisheries Experiment Station)*	*						1934-43
	Results of Fisheries Oceanographic Observations	*	*	*	*			1967-80
	Annual Reports *(Various Regional Fisheries Research Laboratories & Prefectual Fisheries Experiment Stations)*	*	*	*	*			c. 1950-80
	Annual Reports of Joint Fisheries Oceanographic Forecast Project *(Various Groups of*	*	*	*				1965-80

(Continued)

TABLE 1-11. Principal sources of published oceanographic data. (Cont'd)

HEAD AGENCY	DATA REPORTS	DATA TYPE						YEARS/ PUBLICATION
		SERIAL SURVEYS	MBT	XBT	GEK	TIDE	TIDAL CURRENT	
	Prefectual Fisheries Experiment Stations)							
JMA	Results of Marine Meteorological and Oceanographical Observations	*	*	*	*	*	*	1950-80
	Data Reports *(Various Regional Marine Meteorological Observations)*	*	*	*	*	*	*	c. 1950-80
	Oceanographic Prompt Reports *(Various Regional Marine Meteorological Observations)*	*	*	*	*	*	*	
KHO	Technical Reports	*				*	*	1962-80
	Tide Table							Annual
KFRDA	Oceanographic Charts *(Fisheries Experiment Station, Korea)*	*						1927-42
	Annual Report of Hydrographic Observations *(Central Fisheries Experiment Station)*	*						1954-63

(Continued)

TABLE 1-11. Principal sources of published oceanographic data. (Cont'd)

HEAD AGENCY	DATA REPORTS	DATA TYPE						YEARS/ PUBLICATION
		SERIAL SURVEYS	MBT	XBT	GEK	TIDE	TIDAL CURRENT	
	Annual Report of Oceanographic Observations	*	*	*				1964-80
KORDI	Data Processing of the Sectional Oceanographic Observations in Korea, 1: Eastern Sea. *(Ship and Marine Research Institute)*	*						1977
KORDI	Oceanographic Atlas of Korean Waters, Vol. 1: Temperature Structure	*	*	*				1978
UNIV.	Data Record of Oceanographic Observations and Exploratory Fishing *(Hokkaido University)*	*	*	*				1957-80
UNIV.	Preliminary Report of the Hakuho-Maru Cruise *(Ocean Research Institute, Univ. of Tokyo)*	*	*	*	*			Each Cruise

TABLE 1-11. Principal sources of published oceanographic data.

TABLE 1-12. Chronology of JHO data reports on serial observations.

DATA YEAR	DATA REPORT		REPORT YEAR
PRE-WAR PERIOD:			
1923 - 1929	Oceanographic Bulletin	No. 3	1948
1930 - 1931	" "	6	1949
1931 - 1935	Hydrographic Bull., Special	No. 6	1950
1935 - 1938	" " "	8	1951
1938 - 1941	" " "	9	1952
1938 - 1940	" " "	13	1954
1939 - 1941	" " "	16	1955
1931 - 1941	Hydrographic Bulletin	No.69	1962
1941	" "	71	1962
1942	" "	74	1963
1943	Data Report of Hydrographic Observations, Series of Oceanography	No. 2	1966
1944	" "	6	1968
POST-WAR PERIOD:			
1946	Oceanographic Bulletin	No. 1	1947
1946	" "	4	1949
1946 - 1948	Hydrographic Bull., Special	No.10	1953
1947	Oceanographic Bulletin	No. 5	1949
1948	Hydrographic Bull., Special	No. 5	1950
1949	Hydrographic Bulletin	No.14	1949
1949	" "	15	1949
1949	" "	16	1950
1949	Hydrographic Bull., Special	No. 7	1950
1950	" "	14	1954
1951	" "	15	1954
1952 - 1953	Hydrographic Bulletin	No.51	1956
1954 - 1955	" "	58	1959
1956	" "	62	1959
1957	" "	64	1960
1958	" "	66	1961
1959	" "	68	1961
1960	" "	75	1964
1961	" "	77	1964

(To Continue)

TABLE 1-12. Chronology of JHO data reports on serial observations (Continued).

DATA YEAR	DATA REPORT			REPORT YEAR
1962	Data Report of Hydrographic Observations, Series of Oceanography		No. 1	1965
1963	"	"	3	1966
1964	"	"	4	1967
1965	"	"	5	1967
1966	"	"	7	1968
1967	"	"	8	1970
1968	"	"	9	1970
1969	"	"	10	1973
1970	"	"	11	1974
1971	"	"	"	"
1972	"	"	12	1975
1973	"	"	13	1976
1974	"	"	14	1977
1975	"	"	15	1978
1976	"	"	16	1979

TABLE 1-13. Chronology of JFA data reports on serial observations.

"The Results of Fisheries Oceanographical Observations"

DATA YEAR	REPORT YEAR
1951	1969
1952	1970
1963	1966
1964	1967
1965	1968
1966	1969
1967	1970
1968	1971
1969	1972
1970	1973
1971	1974
1972	1976
1973	1978
1974	1979
1975	1980

TABLE 1-14. Chronology of JMA data reports on serial observations.

"Results of Marine Meteorological and Oceanographical Observations"

VOLUME No.	DATA YEAR	REPORT YEAR
12	1950 - 55	1955
13	1950 - 53	1955
14	1954	1955
15	1954	1956
16	1955	1956
17	1955	1957
18	1955	1957
19	1956	1957
20	1956	1958
21	1957	1958
22	1957	1959
23	1958	1959
24	1958	1960
25	1959	1960
26	1959	1961
27	1960	1961
28	1960	1962
29	1961	1962
30	1961	1963
31	1962	1963
32	1962	1964
33	1963	1964
34	1963	1965
35	1964	1965
36	1964	1966
37	1965	1966
38	1965	1967
39	1966	1967
40	1966	1968

TABLE 1-14. Chronology of JMA data reports on serial observations (Cont'd).

"Results of Marine Meteorological and Oceanographical Observations"

VOLUME No.	DATA YEAR	REPORT YEAR
41	1967	1968
42	1967	1969
43	1968	1969
44	1968	1970
45	1969	1970
46	1969	1971
47	1970	1971
48	1970	1972
49	1971	1972
50	1971	1973
51	1972	1973
52	1972	1974
53	1973	1974
54	1973	1975
55	1974	1975
56	1974	1976
57	1975	1977
58	1975	1977

TABLE 1-15: Chronology of serial observational data reports in Korea.

DATA YEAR	DATA REPORTS	REPORT YEAR
	Report of Oceanographic Investigations *Imperial Fisheries Institute (Japan)*	
Apr-Jun, 1922	No. 17,31	1922
Jul-Sep, 1922	No. 18,31	1922
Oct-Dec, 1922	No. 19,33	1923
Jan-Mar, 1923	No. 20,27-30	1923
Apr-Jun, 1923	No. 21,31	1923
Jul-Sep, 1923	No. 22,28	1923
Oct-Dec, 1923	No. 23,31	1924
Jan-Mar, 1924	No. 24,23	1924
Apr-Jun, 1924	No. 25,32	1924
Jul-Sep, 1924	No. 26,35	1924
Oct-Dec, 1924	No. 27,30	1925
Jan-Mar, 1925	No. 28,17	1925
Apr-Jun, 1925	No. 29,25	1925
Jul-Sep, 1925	No. 30,20	1925
Oct-Dec, 1925	No. 31,19	1925
	Oceanographic Charts *Fisheries Experiment Station (Korea)*	
1926	—	1927
1927	—	1928
1928	—	1930
1929	—	1930
1930	—	1931
1931	—	1932
1932	—	1933
1933	—	1934

(To Continue)

TABLE 1-15: (Cont'd) Chronology of serial observational data reports in Korea.

DATA YEAR	DATA REPORTS	REPORT YEAR
1934	–	1935
1935	–	1936
1936	–	1937
1937	–	1938
1938	–	1939
1939	–	1940
1940	–	1941
1941	–	1942
	Annual Report of Hydrographic Observations *Central Fisheries Experiment Station (Korea)*	
1952-53	Vol. 1-2	1954
1954	Vol. 3	1956
1955	Vol. 4	1958
1956-57	Vol. 5-6	1961
1958	Vol. 7	1962
1959	Vol. 8	1963
	Annual Report of Oceanographic Observations *Fisheries Research and Development Agency (FRDA)*	
1960	Vol. 9	1964
1961	Vol. 10	1964
1962	Vol. 11	1964
1963	Vol. 12	1965
1964	Vol. 13	1965
1965	Vol. 14	1967

(CONTINUED)

TABLE 1-15: (Cont'd) Chronology of serial observational data reports in Korea.

DATA YEAR	DATA REPORTS	REPORT YEAR
1966	Vol. 15	1967
1967	Vol. 16	1968
1968	Vol. 17	1969
1969	Vol. 18	1970
1970	Vol. 19	1971
1971	Vol. 20	1972
1972	Vol. 21	1973
1973	Vol. 22	1974
1974	Vol. 23	1975
1975	Vol. 24	1976
1976	Vol. 25	1977
1977	Vol. 26	1978
1978	Vol. 27	1979
	Technical Report *Korea Hydrographic Office*	
1967	pp. 41 - 59	1968
1968	48 - 49	1969
1969	16 - 41	1970
1970	17 - 18	1971
1971	91 - 92	1972
1972	82 - 95	1973
1973-74	148 - 207	1975
1975	220 - 221	1976

2. HISTORY AND STATUS OF OCEANOGRAPHIC DATA COLLECTION

2.1 Historical Perspective

Table 2-1: "Key Oceanographic Events Relating to Straits Around Japan and the Adjacent Waters", summarizes major chronological events relating to the principal data collecting agencies and their data collection efforts. The listed events focus on the Tsushima, Tsugaru and Soya Straits, but some relevant descriptions are also given on the adjacent regions including the East China Sea, the Sea of Japan, and the Sea of Okhotsk.

The historical developments listed in Table 2-1 may be viewed in three successive eras:

<u>Pre-WW II Era</u> (c. 1900-1945):

This era covers some 80 years from the late 19th century when Japan's first institutionalized oceanographic service, Hydrographic Office, was founded (1871), to the end of World War II in 1945. During this period, Japan's oceanographic capabilities took on basic institutional character consisting of three key government services (Hydrographic Office, Fisheries Research Laboratory, and Marine Observatories) and an academic community. Japan also dominated oceanographic activities in Korea during this era. During World War II, oceanographic studies in the adjacent seas of Japan ceased for all practical purposes as the survey vessels were mobilized for war duties away from home waters. The war decimated Japan's oceanographic capability both in materiel and personnel.

Most important data collection activity by Japanese oceanographers during this era took place during 1928-1930 when the Kobe Marine Observatory's Shump Maru cruised the Sea of Japan, and again in 1932-37 when the Imperial Fisheries Laboratory's Soyo Maru I and some 50 participating vessels conducted a simultaneous survey of the Sea of Japan, the Yellow Sea and the East China Sea.

Research on Tsushima Strait probably began with H. Hori's measurements of temperature and density in the West Channel in 1912. His study, covering sectional data at five stations in the study area, was published in:

> Hori, H., 1913. "Oceanographic Investigation of Broughton Strait Made by the Imperial Fisheries Institute Steamer Hayatori Maru." Report of Imperial Fisheries Institute Scientific Investigation, [illegible] 3, 62-66.

TABLE 2-1.

KEY OCEANOGRAPHIC EVENTS RELATING TO
STRAITS AROUND JAPAN AND THE ADDACENT WATERS

YEAR	EVENTS
1867	U.S.S. "Wachusett" surveys approaches to the "Daedong River."
1871	Hydrographic Office is inaugurated within Japanese Navy.
1873	Russian oceanographer L.V. Schrenk identifies "Tsushima Current" in his work: Stroemungsverhaeltnisse im Ochotskischen und Japanischen Meere und in den zunaechst angrenzenden Gewaessern, Memoires de l'Acad. d. Sc., St. Petersbourg, 1873.
1876	Japan's Hydrographic Office begins bathymetric and tidal surveys around Korea and Tsushima Strait.
1888	First oceanographic study of East China Sea, Japan Sea and Okhotsk Sea is carried out by Russian R.V. "Vitiaz I" (Captain S.I. Makaroff). The vessel stayed all year in 1888 in East China Sea and Japan Sea occupying 90 stations (7 of them in Tsushima Strait) and measuring temperature and density at the surface, 25-, 50-, 75-, 100-, 150- and 200- meters. Data as well as analysis of annual SST variation for 1-degree square resolution in Tsushima Strait, based on 220 data points, are included in: Makaroff, S.I., 1894. Le "Vitiaz" et l'Ocean Pacifique. 2 vols., St. Petersbourg.
1893	Dr. Y. Wada conducts Japan's first drift bottle experiments in Kuroshio and Oyashio.
1893	N. Gunji conducts oceanographic expedition to the Kurile Islands. He released drift bottles and cards to investigate the pathway of Oyashio Current.

(TO CONTINUE)

TABLE 2-1.

KEY OCEANOGRAPHIC EVENTS RELATING TO
STRAITS AROUND JAPAN AND THE ADJACENT WATERS

YEAR	EVENTS
1893	Japan's first institutionalized fishery oceanography center "Suisan Chosa-jo" (Fisheries Investigation Office) is inaugurated.
1904	Japan inaugurates "Suisan Koshu-jo" (Imperial Fisheries Institute), the precursor of Imperial Fisheries Experiment Station.
1908	Japan Hydrographic Office publishes the results of its oceanographic surveys in Korean waters titled: "Kankoku Suisanshi" (Fishery Bulletin of Korea), No. 1 The publication lists spring and tidal ranges, charts, description of Tsushima Warm Current, monthly SST distribution at selected locations around Korean peninsula.
1910	Y. Wada publishes annual and monthly average sea water temperature distributions in the Northwest Pacific Ocean.
1912	Japan's first temperature and density measurements take place in the Tsushima Strait, conducted by H. Hori of Imperial Fisheries Institute (precursor of Imperial Fisheries Experiment Station), during October and November 1912 at 10-fathom intervals along a line connecting Busan and Sasuna of Tsushima Island, which approximately agrees with the present 207 Line. Hori, H., 1913. Oceanographic investigation of Broughton Strait (Tsushima Strait) made by the Imperial Fisheries Institute Steamer "Hayatori Maru", Rep. Imp. Fish. Inst., Scientific Investigation, Vol. 3, 62-66.

(CONT'D)

TABLE 2-1.

KEY OCEANOGRAPHIC EVENTS (CONTINUED)

YEAR	EVENTS
1913	Japan's Yamaguchi Prefectural Fisheries Experiment Station conducts hydrographic surveys at three stations along the present 207 Lines (Tsushima West Channel), taking serial measurements at 10-fathom intervals - first sectional serial surveys to take place in Tsushima Strait.
1913-17	Imperial Fisheries Institute (Japan) conducts extensive drift bottle experiments for the purpose of mapping ocean currents adjacent to Japan (principal investigator Y. Wada). A total of 13,337 bottles were released and 2,990 recovered. The chart was exhibited in the 1916 Tokyo Maritime Exposition, and was later included in the posthumous book for Dr. Wada: Kumada, T.(ed.), 1922. Accomplishments of studies on ocean currents around Japan.
1914	S. Ogura of Japanese Hydrographic Office publishes first tidal predictions around Korea and Japan, titled: S. Ogura, 1914. Nippon Kinkai-no Choseki (Tide in the Vicinity of Japan). Revised in 1932. This report was later revised into a more comprehensive treatise of tide in the adjacent seas of Japan and published in Hydrographic Bulletin No. 7, 1932. The new edition, written in English, contained harmonic constants at a total of 704 locations.
1915	Fishery Department of the Governor-General of Korea initiates systematic coastal water temperature measurements (10-day intervals) through participation of local fisheries cooperatives at 12 locations, at the surface, intermediate and bottom layers. This program was later partially taken over by Central Fisheries Experiment Station in the post-WW II years till around 1959.

(TO CONTINUE)

TABLE 2-1.

KEY OCEANOGRAPHIC EVENTS (CONTINUED)

YEAR	EVENTS
1915	T. Kitahara publishes the results of sectional surveys for Tsushima Strait: T. Kitahara, 1915. On the Sectional Observation of Genkainada (East Channel) and Krusenstern (West Channel) Strait, Rep. Imp. Fish. Inst., Scientific Investigation, vol. 4, 40-43.
1916	Fishery Department of the Governor-General of Korea initiates systematic SST measurements at coastal light-house stations around Korea. The program began with 10 stations, which fluctuated variously over the years; there were 40 stations in 1976. Measurements were taken around 10 A.M. daily or every two days. Data between 1916 and 1925 were analyzed by K. Nishida: Nishida, K., 1926. On the surface temperature and specific gravity of the coastal waters of Korea, 1916-1925. Rep. Fisheries Experiment Station, Oceanographic Investigation.
1919	Fishery Department of the Governor-General of Korea establishes six fixed sectional serial survey lines in the Tsushima Strait and its adjacent waters to commence regular sectional oceanographic surveys with its research vessel "Misago Maru I" (62 gross ton, launched 1917). These lines were: A Line: Kuryongpo-Ullungdo-Dokdo (Takeshima) B Line: Busan-Tsushima C Line: Busan-Shimonoseki D Line: Cheju Strait D'Line: Chejudo-Goto Retto E Line: Bikumdo-Daehuksando of which, B Line coincided with the present 207 Line.

(TO CONTINUE)

TABLE 2-1.

KEY OCEANOGRAPHIC EVENTS (CONTINUED)

YEAR	EVENTS
	Initially, the stations extended to no more than 50 miles from the coast. The lines were gradually increased in number to 7 in 1926, 11 in 1930 and 12 in 1935, and accordingly more stations were added to extend to up to 100 miles from the coast. In 1961, the Central Fisheries Experiment Station of the South Korean government renamed all the fixed stations with a total of 262 stations on 25 lines. Data on these fixed stations have been published as follows: 1922 through 1925: Report of Oceanographic Investigation, Imperial Fisheries Institute, vols. 17 through 31. 1926 through 1941: Oceanographic Charts, Fisheries Experiment Station (Korea), 1927 through 1942. 1952 through 1959: Annual Report of Hydrographic Observations, Central Fisheries Experiment Station (Korea), 1954 through 1963. 1960 to date: Annual Report of Oceanographic Observations, Fisheries Research and Development Agency, 1964 to date; and Technical Reports of Hydrographic Office of Korea, 1964 to date.
1920	Imperial Marine Observatory is inaugurated at Kobe as the central oceanographic services in Japan. Fashioned after Germany's "Seewarte" in Hamburg, the observatory was given dual functions: marine meteorology and physical oceanography. The Imperial Marine Observatory produced many eminent oceanographers such as K. Hidaka, K. Suda, M. Uda and T. Ichiye, to name a few. It remained the sole imperial marine observatory till 1942 when another was established at Hakodate. Today, this observatory is called Kobe Marine Meteorological Observatory, one of four regional oceanographic arms of JMA along with those at Hakodate (est. 1942), Nagasaki (est. 1947), and Maizuru (est. 1947).

(TO CONTINUE)

TABLE 2-1.

KEY OCEANOGRAPHIC EVENTS (CONTINUED)

YEAR	EVENTS
1921	Fishery Department of the Governor-General of Korea evolves into Fisheries Experiment Station (Korea), located in Busan. Although 9 more regional fisheries experiment stations were added by 1931, the F.E.S. in Busan remained a principal organization till 1945. After Korea regained its independance in 1945, F.E.S. was renamed briefly as Central Fisheries Experiment Station (1946-62) and in 1963 became the present Fisheries Research and Development Agency. In Tsushima Strait, F.E.S. (Korea), beginning May 1922, continuously surveyed Line 207 (Line B) monthly or bimonthly till 1941, then once to 5 times yearly for 1942 through 1951, and erratically till 1960. The whole survey program was reorganized in 1961 into a permanent network totaling 262 sectional stations on 25 lines. There were 7 lines by 1926, 11 lines by 1930. With the launching of "Misago Maru, II" (153 GT) in 1931, the number of sectional stations was increased to 12 in 1935 with some of them extending to 100 miles offshore.
1922	Japan Hydrographic Office publishes the first issue of "Suiro Yoho" (Hydrographic Bulletin).
1928-30	Imperial Marine Observatory of Kobe conducts its first major study of Japan Sea using its own survey vessel "Syumpu Maru I" (150 gross ton), launched 1927. This study, participated by vessels from prefectural fisheries experiment stations, was the precursor of "Issei Chosa" (simultaneous investigations), an approach which is being used in increasing frequency in recent years in Japan. The study, directed by K. Suda, K. Hidaka and M. Uda, is also the first serious scientific probe into Japan Sea by Japanese oceanographers. As a result of the study, the investigators suggested the possibility of three branches at the extension of Tsushima Current in the Japan Sea. The results of this study became one of the most important contributions to oceanography in Japan prior to the end of World War II:

(TO CONTINUE)

TABLE 2-1.

KEY OCEANOGRAPHIC EVENTS (CONTINUED)

YEAR	EVENTS
1928-30 (Cont'd)	Suda, K. and K. Hidaka, 1930. The result of the oceanographic observation on board "Syumpu Maru" in the southern part of Japan Sea in the summer of 1928. Part 1: Jour. Oceanography (Kaiyo Jiho), Imperial Mar. Obs., 2, 1-73. Part 2: Jour. Oceanography (Kaiyo Jiho), Imperial Mar. Obs., 2, 155-264. Suda, K. and K. Hidaka, 1932. The results of the oceanographical observations on board R.M.S. "Syumpu Maru" in the southern part of the Japan Sea in the summer of 1929. Part 1: Jour. Oceanography (Kaiyo Jiho), Imperial Mar. Obs., 3(2), 291-375. Suda, K. and K. Hidaka, 1932. Results of the second oceanographical observation on board R.M.S. "Syumpu Maru" in the southern part of Japan Sea (July-September, 1929). Jour. Oceanography (Kaiyo Jiho), 3(2), 329-330. Suda, K., K. Hidaka, Y. Matsudaira, E. Kurashige, H. Kawasaki, and T. Kubo, 1932. The results of oceanographical observations on board R.M.S. "Syumpu Maru" in the principal part of the Japan Sea in the summer of 1930. Jour. Oceanography (Kaiyo Jiho), 4(1), 38-40.

(TO CONTINUE)

TABLE 2-1.

KEY OCEANOGRAPHIC EVENTS (CONTINUED)

YEAR	EVENTS
1929	Imperial Fisheries Experiment Station is inaugurated in Japan as the central fishery-oceanographic services, located at Tsuki-jima, Tokyo. The advent of this organization, evolved from the Imperial Fisheries Institute, completed the triad of Japanese oceanographic organization: Hydrographic Office, Imperial Marine Observatory and Imperial Fisheries Experiment Station. In 1949, it became a regional laboratory as Tokai Fisheries Research Laboratory. Today, there are a total of seven regional fisheries research laboratories in Japan.
1931	Hydrographic Office of Japanese Navy conducts 24-hour measurements with current meters at Tsugaru Strait. The result is published in: Suiro Yoho (Hydrographic Bulletin), Japan Hydrographic Office, Vol. 11, No. 11, 1932.
1932-37	An ambitious "simultaneous oceanographic survey" program is conducted in Japan Sea, Yellow Sea and East China Sea by Imperial Fisheries Experiment Station employing its research vessel "Soyo Maru I" (220 gross ton, launched in 1925) along with some fifty small vessels from various prefectural fisheries experiment stations. This program is considered the largest pre-WW II oceanographic program in Japan. Key results of the study are found in: Uda, M., 1934. The results of simultaneous oceanographical investigations in the Japan Sea and its adjacent waters in May and June, 1932. Jour. Imp. Fish. Exp. Station, Vol. 5, 57-190. Uda, M., 1934. Hydrographical studies based on simultaneous oceanographical survey made in the Japan Sea and its adjacent waters during May and June, 1932. Rec. Ocean. Works in Japan, 1(1), 19-107.

(TO CONTINUE)

TABLE 2-1.

KEY OCEANOGRAPHIC EVENTS (CONTINUED)

YEAR	EVENTS
1932-37 (Cont'd)	Uda, M., 1936. Hydrographical studies based on simultaneous oceanographical survey made in the Japan Sea and its adjacent waters during October and November, 1933. Jour. Imp. Fish. Exp. Station, Vol. 7, 91-151.
1941	Japan Oceanographical Society is inaugurated.
1942	Hakodate Marine Meteorological Observatory is inaugurated, and immediately begins oceanographic survey in Soya Strait with its R/V Yushio Maru (150 gross ton). The pre-war survey of Soya Strait by Yushio Maru is reported as follows: Report on Marine Observations in Soya Strait, Hakodate Mar. Obs., Journal of Oceanography, Vol. 1, 1944, 1-62. Surface measurements from a ferry boat across Soya Strait, 1942-1944, were reported in Vol. 2, 1945, 54-83, of the above publication.
1941-45	Japanese Hydrographic Office conducts detailed measurements of currents at Tsushima and Tsugaru Straits, with inconclusive results. Data remain unpublished to date.
1945	Japan Hydrographic Office becomes a civilian department within the Ministry of Transport. In 1948, it is incorporated into Maritime Safety Agency.
1947	Marine Meteorological Observatory is inaugurated at Nagasaki and Maizuru.
1947	Central Fisheries Experiment Station (Korea) resumes oceanographic surveys at fixed stations 4 to 5 times yearly using Pukhansan-ho (74 gross ton).
1949	Japan Fisheries Agency is inaugurated.

(TO CONTINUE)

TABLE 2-1.

KEY OCEANOGRAPHIC EVENTS (CONTINUED)

YEAR	EVENTS
1951	Korean Hydrographic Office is inaugurated within Navy Department.
1952	Korea's Central Fisheries Experiment Station increases sectional survey lines to 12.
1953-57	Japan's Fisheries Agency conducts a 5-year Tsushima Warm Current Research and Development Program (TWCRDP) with participation of both fishery and physical oceanographic communities. Key reports resulting from this program are: Uda, M., 1958. Relationships between oceanographic conditions and fish catches in Japan Sea. Report TWCRDP, Series 1, Vol. 1, Chap. 1, 501-535. Miyata, K., 1958. Characteristics of Tsushima Warm Current in Japan Sea. Report TWCRDP, Series 1, Vol. 2, Chap. 1, 147-152. Kajiura, K., M. Tsuchiya, and K. Hidaka, 1958. Analysis of oceanographic conditions in Japan Sea. Report TWCRDP, Series 1, Vol. 2, Chap. 3, 158-170. Shimomura, T. and K. Miyata, 1957. Oceanographic conditions and water masses in Japan Sea, with special reference to conditions of summer 1955. Rep. Japan Sea Fish. Res. Lab., 6, 23-97.
1954*	Japan initiates "Three agency Oceanographic Liaison Committee," to coordinate oceanographic survey works among three key services: Hydrographic Office of Maritime Safety Agency, Fisheries Research Laboratories of Fisheries Agency, and Marine Observatories of Meteorological Agency (to be formally inaugurated in 1956). The committee later added other participants such as the oceanographic branch of Maritime Self-defense Agency and Marine Science Counselor from the Science and Technology Agency.

(TO CONTINUE)

TABLE 2-1.

KEY OCEANOGRAPHIC EVENTS (CONTINUED)

YEAR	EVENTS
1956	Japan Meteorological Agency is inaugurated.
1961	Central Fisheries Experiment Station (Korea) reorganizes its fixed stations into a total of 262 stations on 25 lines, initiating bi-monthly data surveys at these stations. The surveys now include temperature, salinity, pH, DO, nutrient salts, water color, transparency, wind, cloud, barometric pressure, weather, and occasionally plankton samples.
1963	Fisheries Research and Development Agency (Korea) is inaugurated, evolving from the previous Central Fisheries Experiment Station (Korea). Subsequently, the Agency establishes seven regional stations: Kangnung, Pohang, Yosu, Cheju, Mokpo, Kunsan and Inchon. FRDA is assigned two survey vessels: Paektoosan Ho (150 FT) and Taebaeksan Ho (400 GT).
1963	Japan conducts a three-agency study on the anomalous cold water masses around Japan, including the cold water mass along Tsushima Current in Japan Sea, sponsored by a special research fund set up by the Science and Technology Agency, FY1963. The report was made public by STA entitled: "Report of Special Research Program on Anomalously Cold Water Masses in the Vicinity of Japan: 1964, Research Coordination Department, Science and Technology Agency. The report contains the following general contributions: Fisheries Agency - Data acquisition and analysis relating to the relationships between the cold water masses and biological productivity. Maritime Safety Agency - Development and application of air-borne radiation thermometer.

(TO CONTINUE)

TABLE 2-1.

KEY OCEANOGRAPHIC EVENTS (CONTINUED)

YEAR	EVENTS
1963 (Cont'd)	Meteorological Agency - Research on the relationships between the cold water mass and marine weather using observational tower. The following report was supplemented in 1967: Miyata, K., 1967. Clarification of the decay and patterns of large-scale cold water masses in designated waters - characteristics and fluctuations of the intermediate water in Tsushima Warm Current. Report of the Research on the Influences of Cold Water Mass on the Distribution and Deterioration of Fishery Resources. With Appendices 1 and 2.
1964	Korean Hydrographic Office becomes a department within the Ministry of Transport, detached from Navy.
1965	Japan Oceanographic Data Center (JODC) is inaugurated within Hydrographic Office, Maritime Safety Agency. It was later designated as Kuroshio Data Center (KDC).
1965	Oceanological Society of Korea is inaugurated.
1965	"Cooperative Study of Kuroshio and Adjacent Regions" (CSK) Program commences in May, 1965, with participation of 11 nations including, among them, Japan, Korea, USA and USSR. The study took place in a region bounded by long. 160E and lat. 43N containing South and East China Seas and Sea of Japan. The CSK program focused on: 1. Study of the origin of Kuroshio east of the Philippines and Taiwan. 2. Mixing between Kuroshio and coastal waters in East China Sea. 3. Encounter between Kuroshio and Oyashio.

(TO CONTINUE)

TABLE 2-1.

KEY OCEANOGRAPHIC EVENTS (CONTINUED)

YEAR	EVENTS
1965 (Cont'd)	Through this program, Japan and Korea begin to coordinate respective sectional surveys along fixed lines in Tsushima Strait. The program officially ended in 1970, but the symposia and workshops continued to be held till 1979. Numerous CSK data reports have been published by JODC. See also: Marr, J.C. (ed.), 1970. Kuroshio - A symposium on the Japan Current. East-West Center Press. Stommel, H. and K. Yoshida, 1972. Kuroshio - Its Physical Aspects. Univ. of Tokyo Press.
1968-70	Japan conducts a multi-agency study of Japan Sea to study dynamics of oceanic circulations, eddies and fronts and their relationships to biological productivity. The program produced detailed measurements of current dynamics in both Tshushima and Tsugaru Straits. A number of papers emerged from this program, as well as two official reports by Science and Technology Agency in 1971 and 72. Contributions by various agencies are as follows: Fisheries Agency - Formation and transport of intermediate and bottom waters, their impacts on biological productivity at various designated areas. Maritime Safety Agency - Dynamics of circulations, eddies and fronts; formation and transport of intermediate and bottom waters; current dynamics at Tsushima and Tsugaru Straits. Meteorological Agency - Fluctuation of frontal waters, with special reference to transport, and horizontal and vertical structures of water masses. Geological Institute - Acoustic study of marine geology north of Noto Peninsula.

(TO CONTINUE)

TABLE 2-1.

KEY OCEANOGRAPHIC EVENTS (CONTINUED)

YEAR	EVENTS
1971-73	Japan Fisheries Agency conducts a three-year study on the oceanographic conditions associated with squid fishery grounds in Japan Sea.
1973	Korea Ocean Research and Development Institute is inaugurated within Korean Institute of Science and Technology (KIST). KORDI was renamed in 1974 as Ship and Ocean Research Institute, but regained its original name in April 1978. KORDI has the following departments: Ocean Engineering Dept., Physical Oceanography Dept., Chemical Oceanography Dept., Marine Biology Dept., Marine Economy Dept., Marine Transport and Harbors Dept., Oceanographic Data Center, and Marine Instrumentation. The following publications by KORDI are of particular interest: 1977. Data Processing of the Sectional Oceanographic Observations in Korea. I. Eastern Sea (Japan Sea). 1978. Oceanographic Atlas of Korean Waters. Volume 1: Temperature Structure, ed. Sangbok D. Hahn. KORDI is also involved in the development of tidal power station on the west coast, and in 1978 hosted an international symposium on this subject.
1972-75	Japan Science and Technology Agency sponsors a 4-year comprehensive study of East China Sea participated by Hydrographic Office, Meteorological Agency and Fisheries Agency. Specific objectives of this study were: o Characteristics of coastal water on the continental shelf (JHO). o Mixing of Kuroshio and coastal water (JMA). o Relationship between oceanic conditions and fish resources (JFA).

(TO CONTINUE)

TABLE 2-1.

KEY OCEANOGRAPHIC EVENTS (CONTINUED)

YEAR	EVENTS
1972-75 (Cont'd)	The results of the study were published in: Science and Technology Agency, 1977. Report on Comprehensive Study of East China Sea. 221 p.
1973-75	Japan Science and Technology Agency sponsors a three-year AMTEX (Air Mass Transformation Experiment) study in the East China Sea to investigate air-sea interactions and heat budget of the region as they impact the intensification of migratory extratropical cyclones arriving in Japan. Two data reports AMTEX '74 and AMTEX '75 have been published. The 1973 study focused on the oceanographic structure of Kuroshio in East China Sea using "Hakuho Maru" of University of Tokyo's Ocean Research Institute (leader: Prof. Y. Nagata). The 1974 and 75 studies focused on the measurements and analysis of fluxes of momentum, heat budget and radiation. See: Naito, G., Y. Tsuji and I. Watanabe: Transfer of the fluxes of momentum, sensible heat and latent heat, and the radiation flux in the sea area south of the Nansei Islands in winter. Part 1, AMTEX Report '74. Part 2, AMTEX Report '75.
1975-77	Japan Science and Technology Agency sponsors a 3-year program on the Tsugaru Warm Current region under 3-agency coordination, with the following objectives: o Currents in Tsugaru Strait (JHO) o Bottom topography and submarine geology in the strait (JHO) o Oceanogrpahic structure in the Tsugaru Warm Current region and relationship between fluctuation of oceanographic factors and meteorology (JMA).

(TO CONTINUE)

TABLE 2-1.

KEY OCEANOGRAPHIC EVENTS (CONTINUED)

YEAR	EVENTS
1975-77 (Cont'd)	o Relationship between distribution and migration of fishing grounds and fluctuation of oceanographic factors. The results of this study was published as: Science and Technology Agency, 1979. Report of the comprehensive study on the Tsugaru Warm Current Region. 335 p.
1976-78	Japan Science and Technology Agency sponsors a 3-year study on the Sea of Okhotsk under a three-agency coordination. Among the objectives of the study were: o Oceanography of Soya Warm Current o Oceanography off Kurile Islands o Dynamics of sea ice o Characteristic water masses o Interpretation of imagery from NOAA-series satellite The results of the study were published in: Science and Technology Agency, 1981. Report on Comprehensive Study of the Sea of Okhotsk. 248 p.

The first current meter survey in the West Channel using Ekman-Merz current meter was conducted by K. Nishida of Korean Fisheries Experiment Station in 1923.

Serial oceanographic observations along sectional lines began in 1919 when a newly launched Misago Maru (63 gross ton, launched in 1917) occupied six survey lines in the vicinity of Tsushima Strait. These lines were located as follows:

A line: Kuryongpo-Ullungdo-Dokdo

B line: Busan-Tsushima

C line: Busan-Shimonoseki

D line: Cheju Strait (Cheju-Soando)

D'line: Cheju-Goto Islands

E line: Bikumdo-Daehuksando

The B line, with its six stations, corresponded to the present 207 line which traverses the West Channel of Tsushima Strait - one of the most heavily surveyed lines in Korean waters.

Between 1919 through 1921, the survey along these sectional lines were sporadic, but a scheduled survey program on a monthly and bi-monthly basis commenced in 1922. More lines were added over the years, increasing to a total of 10 by 1945. One of these lines was the U line, which corresponded to the present 208 line traversing the immediate north side of Tsushima Strait's West Channel. The U line had only six stations when initially established in 1926, extending to only 43 miles from Ulgi, but four more stations were added in 1936 to extend the line full-length to Kawajiri-Misaki on Honshu, Japan, thus traversing the entire width of the Tsushima Strait.

Surveys along the sectional lines continued till 1944, and the results were analyzed and published by Fisheries Experiment Station of the Governor-General of Korea in a series of data reports titled:

Annual Report of Hydrographic Observations,
Volumes 1 - 9, 1926 through 1941.

In the Tsugaru Strait, the Kobe Marine Observatory's Shumpu Maru I conducted a limited survey in 1930, followed by a 24-hour current measurement by the Hydrographic Office in 1931. The Hydrographic Office conducted more detailed measurements of current in the Tsugaru as well as Tsushima Straits in 1941-45, but the results remain unpublished till today.

In the Soya Strait, the only pre-war survey that occurred was a cruise by the Hakodate Marine Observatory's Yushio Maru in 1942.

Rebuilding Era (1946-63):

Effective rebuilding of oceanographic capabilities did not begin in Japan till after 1950 when the breakout of the Korean War gave impetus to its economy, and in Korea till after around 1960.

In 1947, Japan's oceanographic institutions underwent major reorganization and expansion. In this year, the Japanese Hydrographic Office was transformed into a civilian service as a department within the Maritime Safety Agency under the Ministry of Transport. The Fisheries Agency was inaugurated in this year, and subsequently its regional Fisheries Research Laboratory was gradually expanded to a network of eleven. In 1947, two new marine meteorological observatories were created at Nagasaki and Maizuru, completing a network of five regional centers along with those at Kobe, Hakodate, and Tokyo. In 1956, these observatories were placed under the newly inaugurated Meteorological Agency.

Already in 1953-57, the Fisheries Agency carried out a 5-year study program on the Tsushima Warm Current. The Hakodate Marine Meteorological Observatory's Yushio Maru resumed routine surveys in the Tsugaru Strait in 1949 and in the Sea of Okhotsk in 1955. Observations at the Tsushima Strait were considerably reinforced in 1960 with the advent of Chofu Maru of the Nagasaki Marine Meteorological Observatory. In the early 1960's, the Japanese survey vessels began to be equipped with BT and GEK. As the oceanographic survey activities by the three agencies grew in scope by mid-1950, a liaison mechanism was created to coordinate cruise tracks and schedules among them. In 1963, Japan's first post-war 3-agency joint survey was conducted under the financial management of the Science and Technology Agency, focusing on the dynamics and fishery implications of cold water masses in the Sea of Japan.

In Korea, a tangible sign of recovery began to emerge as late as 1961, when the then Central Fisheries Experiment Station expanded its fixed stations into a total of 262 stations on 25 lines fully surrounding the coastlines south of the DMZ. In 1963, the CFES was formally evolved into Fisheries Research and Development Agency.

Recent Era (1964 - Present):

During this era, the quality as well as the quantity of data acquisition efforts saw remarkable improvements in Japan and Korea. This era was also characterized by the increasing amount of

international coordination for data acquisition and data exchange, and the sophistication in the quality of research. Both in Japan and Korea, the entire fleet of active oceanographic survey ships was built during this era.

In Japan, in addition to routine cruises along the numerous fixed serial stations by regional agencies, multi-year 3-agency joint studies emerged as a new trend for oceanographic data acquisition. Studies of this type which took place during this era included the Cooperative Study of Kuroshio (1965-79) and the WESTPAC (1979-) programs, the comprehensive studies on the Sea of Japan (1969-70), the East China Sea (1972-75), the Tsugaru Warm Current (1975-77), and the Sea of Okhotsk (1976-78). The Japan Meteorological Agency began deploying ocean data buoys in 1973, and also began VHRR data reception from U.S. environmental satellites in 1968.

In Korea, this era marks the coming-of-age of its oceanographic capability. In 1964, the Hydrographic Office evolved into a civilian department under the Ministry of Transport and began undertaking serial oceanographic surveys in the southern waters (Stations 200 series) as well as tide measurements at a total of 16 stations by 1980. The Korean Ocean Research and Development Institute was inaugurated in 1973 to add an important research arm to the Korean oceanographic community. A sizable number of distinguished oceanographers have also emerged in Korea during this era.

An important development during this era was the creation of Japan Oceanographic Data Center within the Hydrographic Office in 1965. Beginning in 1966, the JODC undertook computer-based data archiving efforts encompassing the full range of oceanographic data being collected in Japan.

2.2 Patterns and Trends

Data Volume

The amount of data being collected by the Japanese and Korean agencies has increased by leaps and bounds in recent years. For instance, ocean current measurements using GEK, which began around 1953 in Japan, averaged 6,000 annually during the past 15 years as shown in Figure 2-1. Most of the GEK data are taken in the adjacent seas of Japan. According to a recent tally by the JODC, as many as 20,000 oceanographic stations, 15,000 MBT casts and 8,000 GEK measurements are being taken annually in Japan. The upward trend of data collection would undoubtedly sustain or even accelerate in the

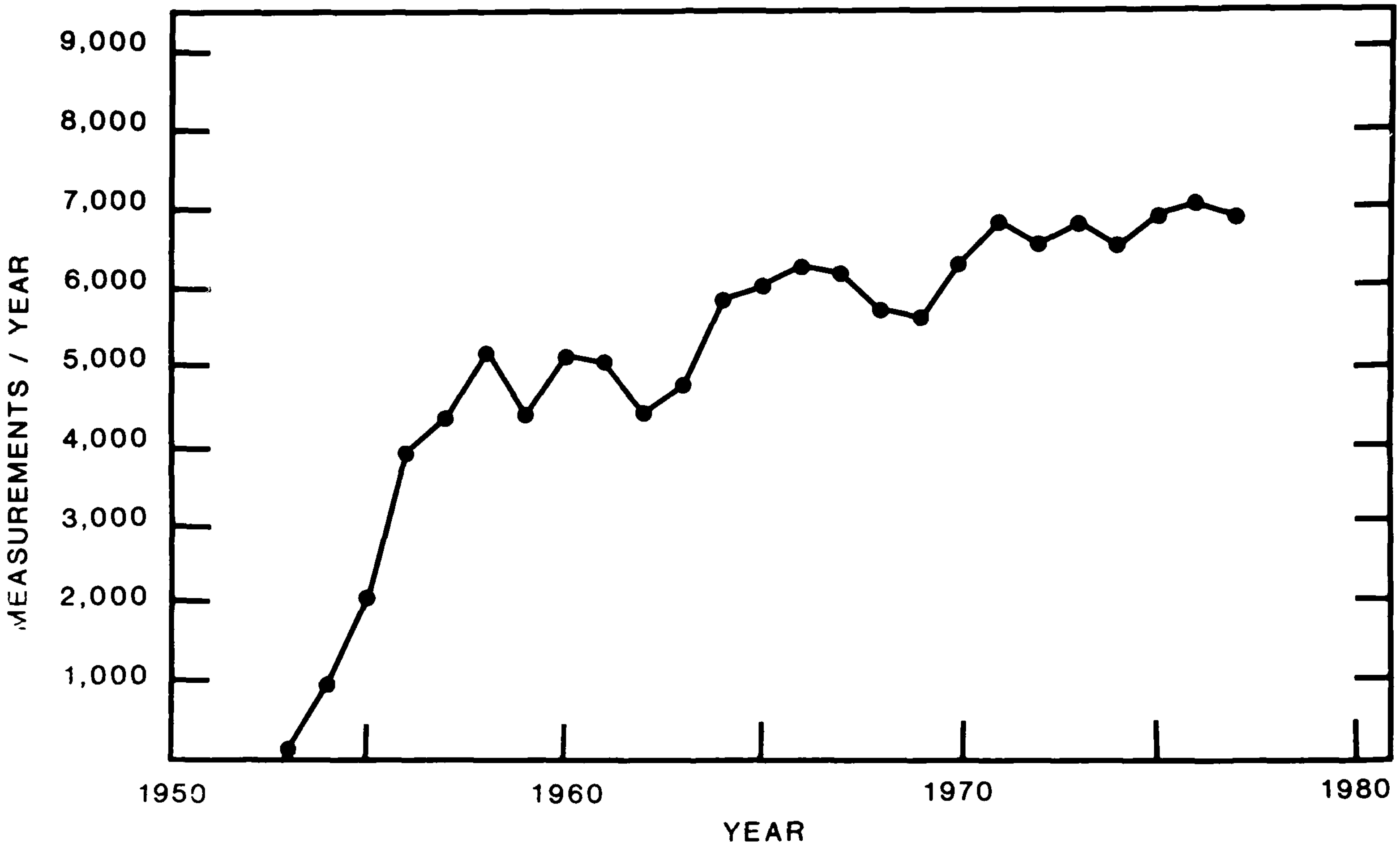


Figure 2-1. Annual GEK stations on file at JODC, 1955-1977.

years ahead both in Japan and Korea, as a greater emphasis is being placed on pollution monitoring and fisheries productivity in domestic waters.

Multi-agency Operations

There is an increasing trend for joint cruises among different agency units on local, regional and national levels. The first simultaneous operation was carried out in 1932 when the fisheries research vessel Soyo Maru I and some 50 small vessels from every prefecture facing the Sea of Japan participated in a joint study of the Yellow Sea, the East China Sea and the Sea of Japan under the leadership of the then Imperial Fisheries Experiment Station (presently, Tokai Fisheries Research Laboratory). A joint operation was repeated in 1933, again in 1934 at a reduced scope, and once again in 1941.

Since the first simultaneous operation in 1932, coordinated cruises among adjacent prefectural fisheries experiment stations have become a routine practice. In the post-war years, multi-agency coordination took on a more systematic pattern. Since around 1946, regional agencies of the JHO, the JFA, and the JMA began holding annual liaison workshops, and subsequently included local representatives of the Maritime Self-Defense Agency. This regional coordination was organized into the following three groups:

Tohoku (Northeast) Region:

Hakodate Marine Observatory
Fish. Res. Labs, Hokkaido, Tohoku & Tokai
Maritime Safety Agency, Region 2
Maritime Self-Defense Agency, Ominato District

Western Region:

Nagasaki Marine Observatory
Fish. Res. Lab., Nansei-kai Region
Maritime Safety Agency, Regions 7 & 10
Maritime Self-Defense Agency, Sasebo District

Japan-Sea Region:

Maizuru Marine Observatory
Fish. Res. Lab., Japan-Sea Region
Maritime Safety Agency, Regions 2 & 9
Maritime Self-Defense Agency, Maizuru District

Inter-agency liaison activity among the headquarters representatives began around 1954, with regular participation from the JHO, the JFA, the JMA, the Science and Technology Agency, and the Maritime Self-Defense Agency.

A number of major inter-agency projects evolved from these coordination activities. The first post-war inter-agency joint study was a JFA-JMA 5-year project (1953-57) on the Tsushima Warm Current. Subsequently, a series of inter-agency joint studies were performed involving the three key services, i.e. the JHO, the JFA and the JMA, and other agencies such as the Geological Survey, universities and prefectural fisheries experiment stations. These studies were called "Sogo Kenkyu" (Comprehensive Study), and were managed by the Science and Technology Agency. This "Comprehensive Study" approach has been applied to the cold water masses downstream of the Tsushima Strait (1963), the Sea of Japan (1969-70), the East China Sea (1972-75), the Tsugaru Warm Current (1975-77), and the Sea of Okhotsk (1976-78).

International Coordination

The CSK (Cooperative Study of the Kuroshio and Adjacent Regions) program during 1965-77 was an important milestone in the development of oceanographic knowledge in the adjacent seas of Japan. It also served as an excellent opportunity for testing and training the Korean oceanographic community. Japan undertook management responsibility for project coordination as well as for data archiving efforts for CSK. The Japan Oceanographic Data Center, also serving as the Kuroshio Data Center, has recently compiled a CSK data inventory titled "Guide to CSK Data" (March, 1981), giving a complete inventory of its CSK data holdings.

Table 2-2 summarizes the serial observational data which emerged from the CSK field programs between 1965 and 1973. It is evident that Japan accounted for nearly 40% of the data, much of it contributed by the JMA and the JHO. The Republic of Korea contributed an impressive 18%.

The CSK program also provided conditions favorable to international coordination of serial observational cruises between Japan and Korea. The Korea Fisheries Research and Development Agency began coordinating bimonthly serial observation cruises at 63 fixed stations with Japan. Between 1971 and 1974, the Korea Hydrographic Office undertook coordinated serial observational cruises in the Tsushima Strait with Japan. Both of these Korean agencies are actively participating in a data exchange with the JODC.

TABLE 2-2. Summary of serial observational stations taken by participating nations in the CSK program.

COUNTRY CODE	COUNTRY	NUMBER OF STATIONS	OBSERVED YEAR
21	China	290	1965 - 69
24	Korea, Rep. of	2,311	1965 - 71
31	U.S.A.	473	1965 - 69
42	Indonesia	325	1967 - 71
66	Philippines	196	1968 - 69
74	United Kingdom	597	1965 - 71
86	Thailand	581	1967 - 69
90	U.S.S.R.	2,830	1965 - 71
MS	Malaysia	150	1970 - 71
	Sub-Total	7,753	

49	Japan		
	JHO	1,308	1965 - 73
	JMA	2,535	1965 - 72
	JFA	209	1965 - 71
	Univ.	876	1965 - 71
	Sub-Total	4,928	
	Total	12,681	

Source: JODC Serial Observation Data File to October, 1973.

2.3 Status of Data Archiving

The JODC, founded in 1965, serves as a central repository of oceanographic data in Japan. Whereas most of the data collected by various organizations in Japan would in due course of time be submitted for centralized storage at the JODC, such submission is not compulsory, and therefore, the current data holdings at the JODC should not be considered as complete. For instance, the Ports and Harbors Bureau is continuing the policy to store observational data at the site of its local data collectors. This applies to coastal wave data, tide and tidal current data, and temperature data, mostly originating in the nearshore zones, bays, estuaries, and port locations.

Data archiving patterns in Japan, by data type, are as follows:

Serial observation: Almost all the data obtained by the JHO, the JFA, the JMA, and universities, and some recent data by the Maritime Self-Defense Agency and the Korean agencies (Fisheries Research and Development Agency, and Hydrographic Office) are assembled at the JODC. Table 2-3 shows the amount of serial observational data which had been processed into a magnetic-tape files for cruise and station inventories at JODC as of May 31, 1980. A total of nearly 120,000 serial observations from domestic sources and more than 100,000 from foreign sources have been processed into JODC inventories.

MBT, XBT and GEK: The JMA operates a real-time data telemetry system ADESS (Automatic Data Editing and Switching System) to centralize the data transmission from its own ships and some of the JHO ships at sea. Non real-time data are forwarded to the JODC and stored on mag-tape under the IGOSS, cruise, and station inventories.

Table 2-4 summarizes the amount of the processed MBT and XBT data at the JODC as of May 31, 1980. More than 43,000 from domestic and about 145,000 from foreign sources have been processed. Data from Japanese sources are dominantly from the adjacent seas of Japan. Table 2-5 summarizes the processed GEK data at the JODC as of the same date, giving a total of more than 130,000 data points. Most of the GEK data were taken within 200 miles from the Japanese coasts, whereas the foreign data were based on ship-drift measurements.

SST: Almost all the data, except for those collected by prefectural fisheries stations are reported to ADESS, which are eventually assembled at the JODC.

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TABLE 2-3. Summary of serial observational data on magnetic-tape file at JODC as of May 31, 1980.

COUNTRY CODE	COUNTRY	DATA YEARS	STATIONS	CSK	STS.	SUB-TOTAL
06	West Germany	1906-1907, 1955-1965	289			289
08	Brazil	1957-1964	333			333
09	Auatralia	1938-1968	8,295			8,295
18	Canada	1927-1971	14,056			14,056
20	Chile	1948-1949, 1959-1972	542			542
21	China	1962-1963	64	1965-1969	290	354
22	Colombia	1964-1966	200			200
24	Korea, Rep.	1930-1934, 1971-1972	1,573	1965-1975	2,518	4,091
26	Denmark	1914-22, 1928-29, 1951-52	252			252
28	Ecuador	1958, 1963-1972	733			733
31	U.S.A.	1928-29, 1933-41, 1946-74	53,375	1965-1969	473	53,848
32	Ethiopia	1966-1968	155			155
35	France	1949-1950, 1956-1973	1,274			1,274
41	India	1964	1			1
42	Indonesia	1949, 1956-1957, 1964-1973	969	1967-1973	351	1,320
57	Mexico	1963	50			50
58	Norway	1920-1922	3			3
59	New Caledonia	1956-1965	392			392
61	New Zealand	1954-1964, 1971	449			449
62	Pakistan	1964	8			8
64	Netherlands	1929-1930	523			523
65	Peru	1961-1974	3,879			2,879
66	Philippines			1968-1969	196	196
74	United Kingdom	1911, 1930-38, 1950-52, 1963-66	587	1965-1971	597	1,184
77	Sweden	1947-1948	62			62
86	Thailand	1956-57, 1967, 1970-1973	547	1967-1972	758	1,305
90	U. S. S. R	1925-27, 1932-33, 1956-73	7,033	1965-1977	4,874	11,907
95	Yugoslavia	1959	1			1
MS	Malaysia			1970-1971	150	150
		SUB-TOTAL	95,645		10,207	105,852
49	Japan					
	JHO	1923-24, 1927-43, 1946-79	21,293	1965-1977	1,973	23,086
	JMA	1947-1979	27,913	1965-1977	5,600	33,513
	JFA	1933-44, 1947-53, 1956, 1958 1961, 1963-64, 1970-79	56,366	1965-1974	337	56,703
	UNIV.	1935-1939, 1953-1975	3,050	1965-1975	1,044	4,094
	DA	1976-1978	319			319
		SUB-TOTAL	108,941		8,774	117,715
TOTAL		1906-1979	204,586	1965-1977	18,981	223,567

TABLE 2-4. Summary of BT data on magnetic-tape file at JODC, as of May 31, 1981.

COUNTRY CODE	COUNTRY	MBT		XBT		SUB-TOTAL
		DATA YEAR	STATIONS	DATA YEAR	STATIONS	
09	Australia	1944, 1955 71	4245	1972–1974	624	4869
18	Canada	1958	39			39
20	Chile	1966	149			149
24	Korea, Rep			1970	53	53
31	U. S. A.	1943 1971	99355	1966–1974	39486	138841
61	New Zealand	1964 1970	81	1970–1974	312	393
64	Netherlands	1970	122	1970	[illegible]	[illegible]
74	U. K.	1950 1960	617			[illegible]
86	Thailand	1961	24			[illegible]
	SUB-TOTAL	1943–1971	104662	1966–1974	[illegible]	[illegible]
49	Japan	1955–1958, 1960–1963 1965, 1968 72, 1976–1979	27484	1976–1979	[illegible]	30484
	SUB-TOTAL		27484		[illegible]	[illegible]
	TOTAL	1943–1979	132146	1966–1979	[illegible]	[illegible]

TABLE 2-5. Summary of GEK data on magnetic-tape file at JODC, as of May 31, 1981.

DATA YEAR	JHO	JMA	JFA	DA	UNIV.	USSR	SUB-TOTAL
1953	86						86
1954	1,001						1,001
1955	1,907	198					2,105
1953-1955	2,994	198					3,192
1956	2,957	933					3,890
1957	2,739	1,564			43		4,346
1958	3,566	1,546			109		5,221
1959	2,971	1,437					4,408
1960	3,651	1,497					5,151
1956-1960	15,887	6,977			152		23,016
1961	3,318	1,712			46		5,076
1962	2,934	1,478			39		4,451
1963	2,916	1,820					4,736
1964	3,038	1,949	820				5,807
1965	3,431	1,961	590		31		6,013
1961-1965	15,637	8,920	1,410		116		26,083
1966	3,692	1,893	610		85		6,280
1967	3,253	1,976	755		182		6,166
1968	3,454	1,191	707		140	123	5,615
1969	3,295	1,559	658		15	20	5,547
1970	3,094	1,803	770	106	58		5,831
1966-1970	16,788	8,422	3,500	106	480	143	29,439
1971	3,437	1,810	1,421	64	52		6,784
1972	3,271	1,688	1,338	69	139		6,505
1973	3,951	1,505	1,000	151	171		6,778
1974	3,381	1,221	631	537	241		6,011
1975	3,431	1,413	985	416	178		6,423
1971-1975	17,417	7,637	5,375	1,237	781		32,501
1976	3,413	1,333	1,015	618	172		6,551
1977	3,070	1,524	1,143	674			6,411
1978	2,809	(1,096)	(428)				(4,333)
1979	(1,042)	(914)	(124)				(2,080)
1976-1979	10,344	4,867	2,710	1,292	172		19,375
	79,111	37,021	12,995	2,635	1,701	143	133,606

Tide: The JODC compiles daily average sea levels from the JMA and JHO tide stations and the National Geographical Institute's Coastal Sea Level Center into a mag-tape tide file. Some of the data collected by the Ports and Harbors Bureau are forwarded to the JMA.

Tidal Current: The JHO, the JMA, and the Ports and Harbors Bureau store their respective data in house. The JODC processes only the JHO data into a mag-tape tidal current file.

Wave: The JMA coastal wave stations forward the data to the ADESS. The data collected at a total of 12 coastal stations under the Ports and Harbors Bureau are assembled at the Ports and Harbors Research Institute. The JODC has no coastal wave data file. Most of the high-seas wave data being obtained by the JHO, the JMA and other cooperating vessels are forwarded to the ADESS. The JODC archives only the statistics of high-seas wave data.

Ocean Pollution: All the data from the ocean pollution survey cruises by the JHO, the JMA and the Japan Environmental Protection Agency, are processed into an ocean pollution data file on magnetic tape at the JODC.

Sea Ice: Real-time data on sea ice is forwarded and archived at the Drifting Ice Information Center of the Region V Maritime Safety Agency (Otaru) and at the Hakodate Marine Meteorological Observatory.

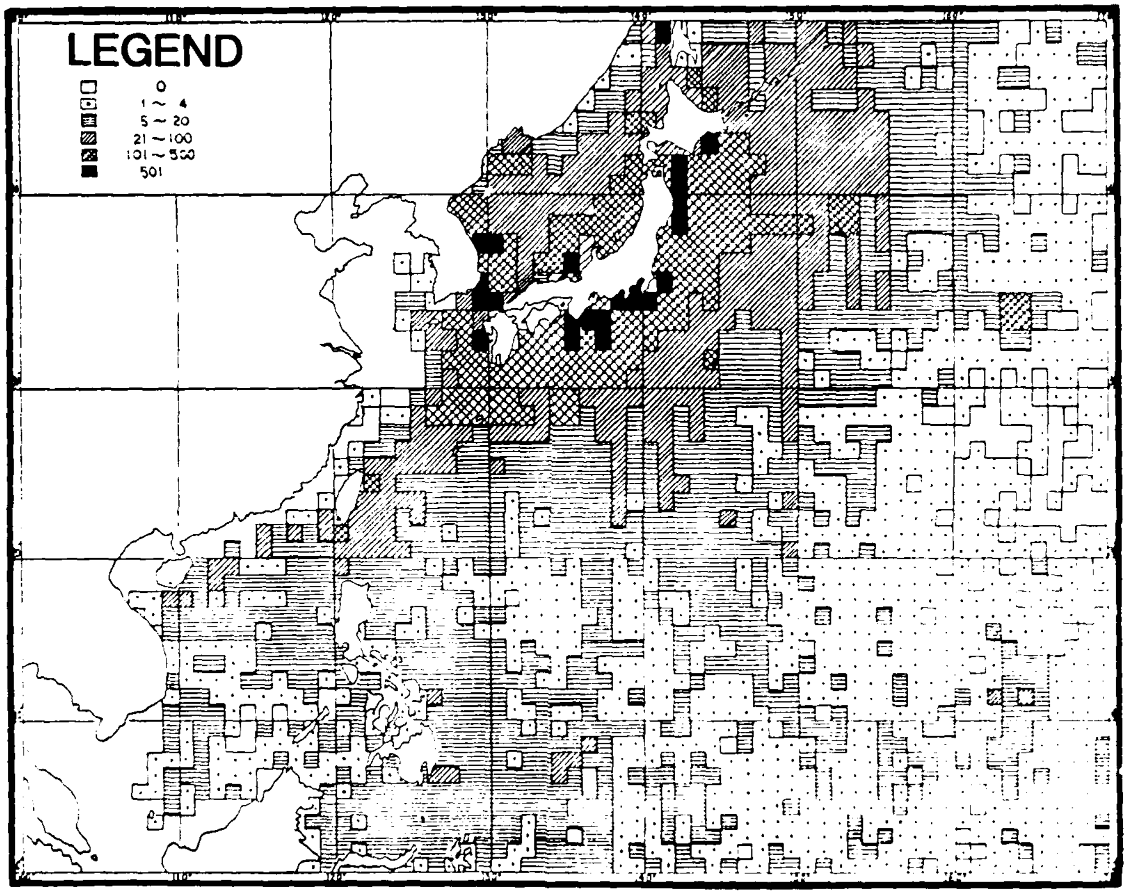
Sea Fog: Observation of sea fog is an exclusive responsibility of the JMA, which also acts as a sole repository of this data.

Data Buoy: Real-time ocean buoy data is disseminated only within the JMA and to prefectural fisheries experiment stations. Data sheets are forwarded to the JODC for archiving.

Figure 2-2 shows distribution of serial observation stations at a 100-m depth on file at the JODC, at a 1° Marsden-square resolution. One recognizes high density of serial stations in the Tsushima Strait, on the downstream side of the Tsugaru Strait, and along some portion of the west coast of Sakhalin. Data in the Soya Strait is relatively sparse. A moderately high data density exists along the paths of the Kuroshio and Oyashio in the Pacific Ocean and of the Tsushima Warm Current in the East China Sea and inside the Sea of Japan. (See a Marsden Square chart in Figure 2-3).

Figure 2-4 shows GEK surface current data distribution at a ¼-degree Marsden-square resolution in the adjacent seas of Japan, derived from a JODC GEK data file, 1953-1977. Of the three sea

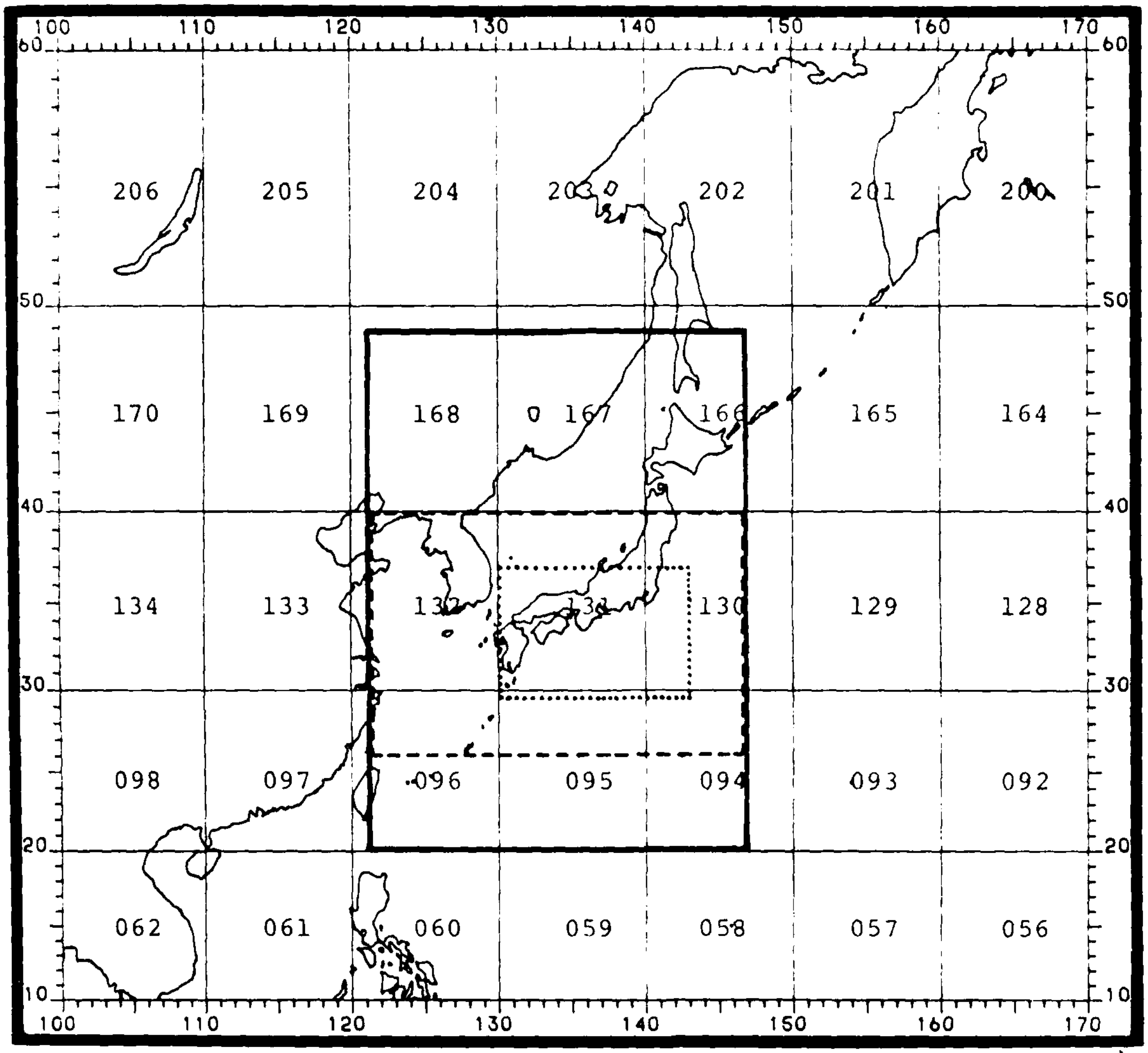
SERIAL STATION DATA DENSITY TO OCT 1973



100-m LAYER

(Courtesy of JODC)

Figure 2-2. Serial observational data distribution in 1° squares on file at JODC, to October 1973.

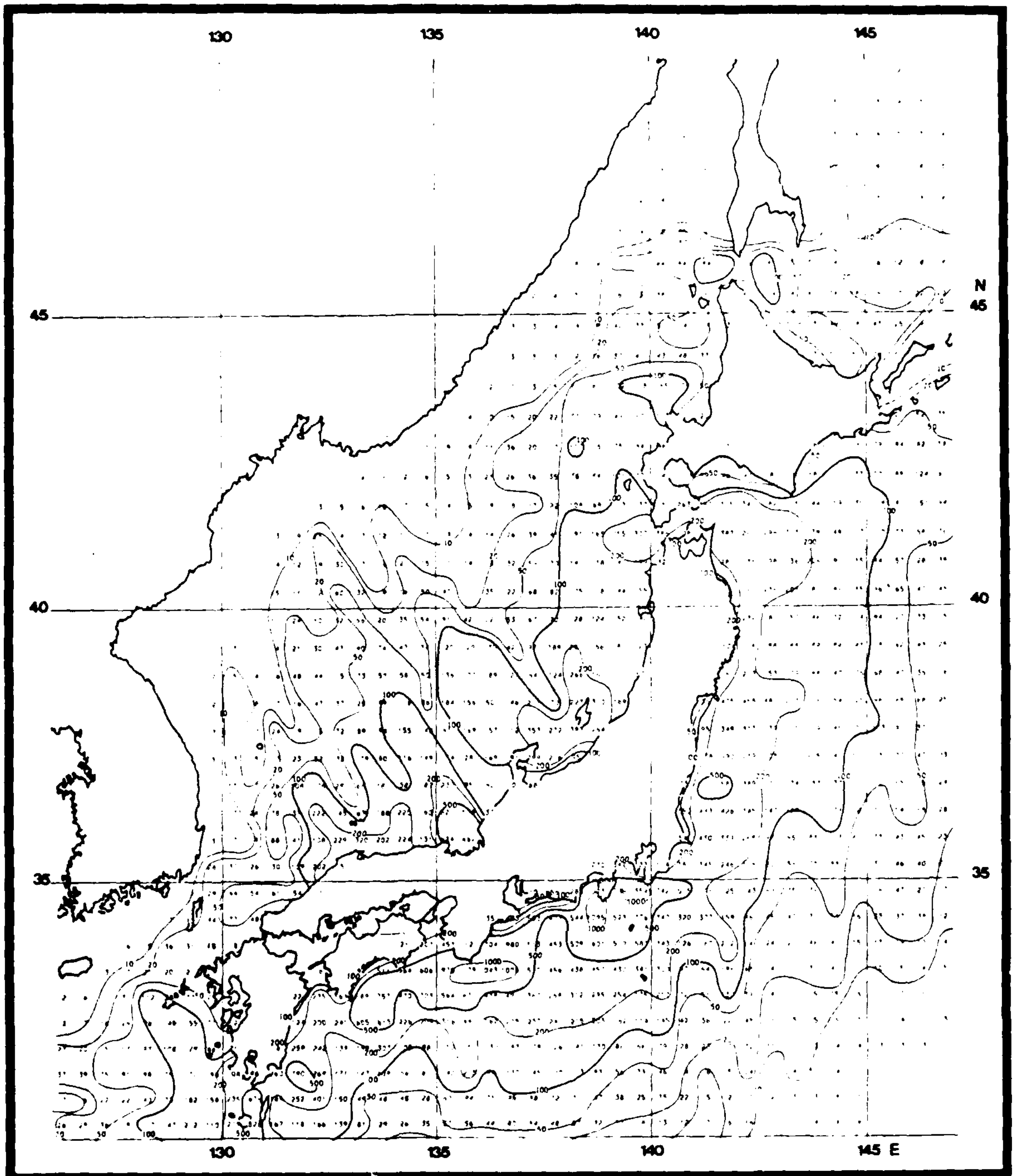


(Courtesy of JODC)

————	**Adjacent Seas of Japan**
- - - - - -	**Adjacent Seas of Japan**
··········	**Off South Coast of Japan**

Numerals: 10° Marsden Squares

Figure 2-3. Marsden square chart in the Adjacent Seas of Japan.



(Courtesy of JODC)

Figure 2-4. GEK data distribution in 1/4-degree Marsden squares on file at JODC, 1953-1977.

straits under study, the GEK data density is highest in the Tsugaru Strait, averaging more than 300 data points per ¼-degree square in the channel and about 200 outside the channel. The data density per ¼-degree square in the Soya Strait averages slightly more than 100, and in the Tsushima Strait, less than 100. The GEK data in the Tsushima Strait is concentrated in its east channel.

Table 2-6 shows data volume for each of the sea strait regions, based on the most recent tabulation (1981) of vertical summary and GEK data statistics from the JODC file. Serial observational data (temperature and salinity), are most numerous in the Tsugaru Strait, followed closely by the Tsushima Strait. Data density of serial stations for the Soya Strait, lags far behind the Tsugaru and Tsushima Straits. Regarding the GEK data, the Tsugaru Strait again has the most number of measurements, followed by the Soya and the Tsushima Straits, in the order named.

Table 2-7 shows a detailed breakdown of data density at a 1-degree-Marsden square resolution for each sea strait, derived from a recent 1981 tabulation furnished by the JODC.

Korea

Data archiving effort in Korea is in developing stage. The Fisheries Research and Development Agency, the Hydrographic Office, and the Ocean Research and Development Institute maintain a respective data center within each organization. The JODC has most of the Korean serial observations on its magnetic-tape file.

Table 2-8 shows a summary of serial observation stations by Korean agencies for a period 1961 through 1975, compiled by the KORDI, 1978. Figure 2-5 shows a bimonthly breakdown of the same statistics. As previously shown in Figure 1-7, the stations of 200's series are located in and adjacent to the Tsushima Strait. One recognizes a comparatively high data density in the West Channel of the Tsushima Strait. The number of serial stations in the Tsushima West Channel (Lines 206, 207 and 208) over the same period was, respectively, 375, 533 and 477, with a combined total of 1,378.

NODC

The National Oceanographic Data Center (NODC) serves as World Data Center A, and, in this capacity, is engaged in archiving world-wide oceanographic data in accordance with an IOC agreement. The rate of accumulation of international oceanographic data at the NODC has been accelerating in recent years.

SEA STRAIT	DATA VOLUME		
	TEMPERATURE	SALINITY	GEK
Tsushima	51,080	48,782	2,502
Tsugaru	58,837	53,996	6,723
Soya	10,127	8,956	1,925

(Courtesy of JODC)

TABLE 2-6. Data volume in the JODC file for the sea strait regions, to May, 1981.

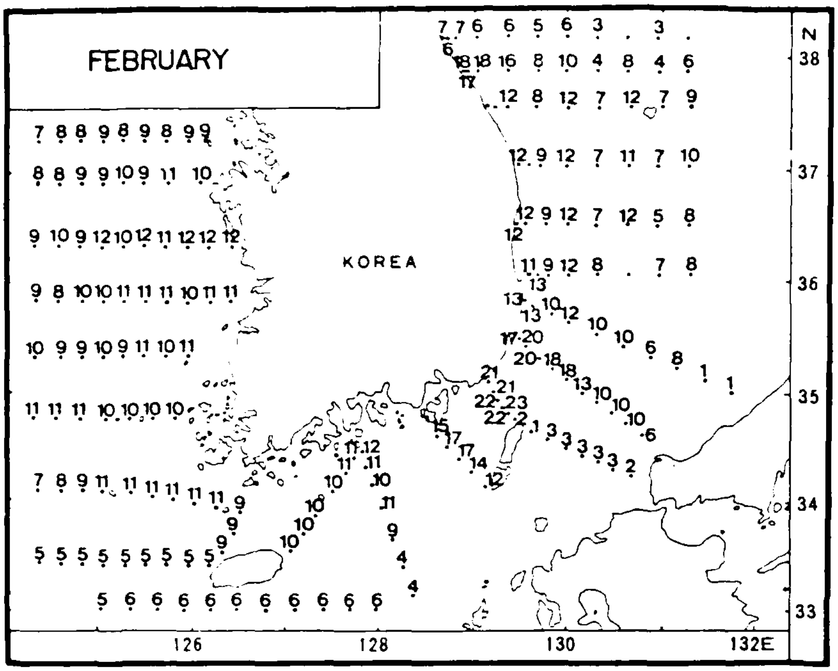
TABLE 2-7. Detailed breakdown of sea strait data in JODC file, to May, 1981

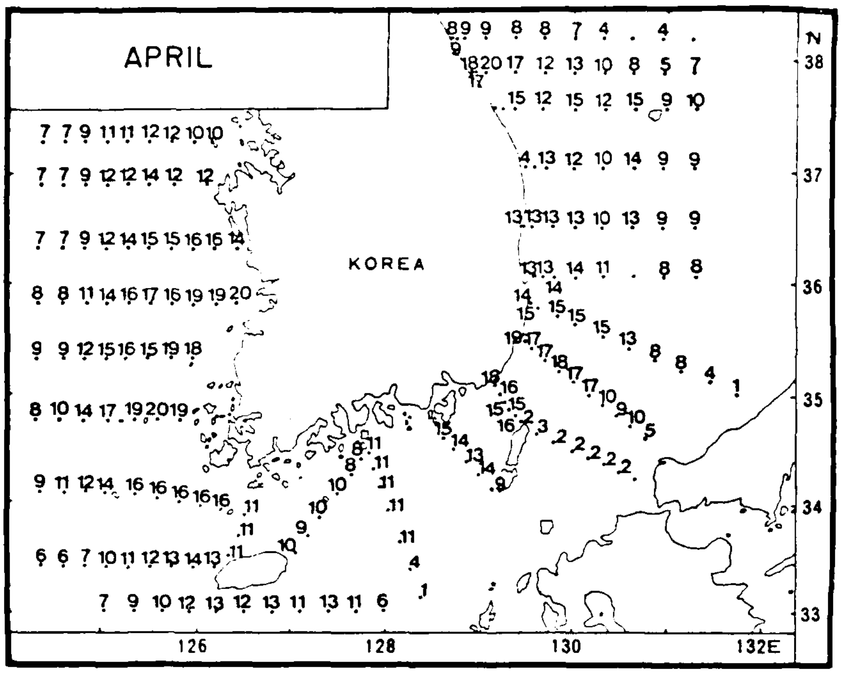
SEA STRAIT	MARSDEN SQUARE		NUMBER OF STATIONS		
	10°	1°	TEMPERATURE	SALINITY	GEK
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE 2-8. Summary of serial observational stations by the Korean agencies during 1961-1975.

STATION NO.	MONTHS OF CRUISE						SUBTOTAL
	FEB.	APR.	JUN.	AUG.	OCT.	DEC.	
306	75	89	86	85	81	62	478
307	74	85	62	78	77	59	435
308	109	125	107	102	102	74	619
309	102	148	103	129	112	74	668
310	79	113	87	104	82	69	534
311	73	106	90	106	83	69	527
312	90	126	111	137	93	93	650
313	45	92	89	80	33	69	408
314	65	117	138	120	91	67	598
SUBTOTAL	712	1,001	873	941	754	636	4,917
203	27	33	36	45	18	18	177
204	62	55	56	76	42	35	326
*205	61	60	54	81	43	43	342
*206	75	65	65	64	58	48	375
*207	129	95	120	136	107	75	662
*208	142	139	127	140	160	102	810
*209	84	108	99	112	105	86	594
SUBTOTAL	580	555	557	654	533	407	3,286
102	68	77	90	94	95	84	508
103	77	93	102	102	84	73	531
104	68	71	89	91	83	106	508
105	67	88	90	86	78	71	480
106	109	127	148	148	125	118	775
107	43	66	59	70	66	65	369
SUBTOTAL	432	522	578	591	531	517	3,171
GRAND TOTAL	1,724	2,078	2,008	2,186	1,818	1,560	11,374

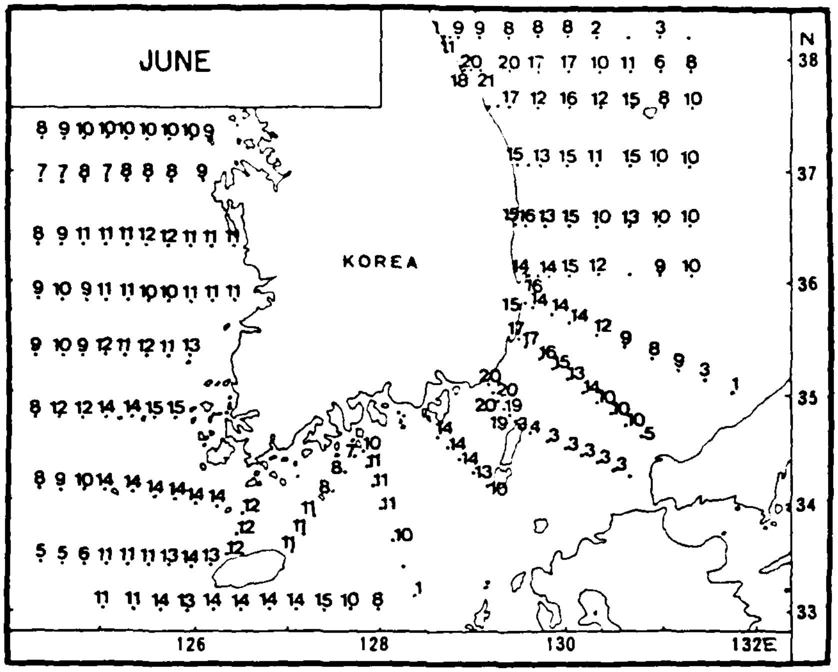
(*) Tsushima Strait Region

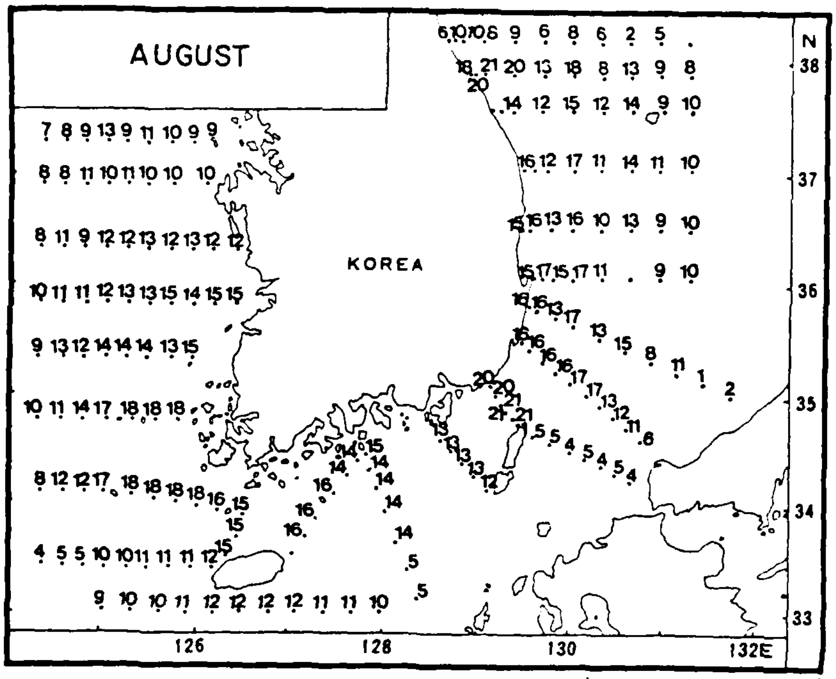




(Courtesy of KORDI)

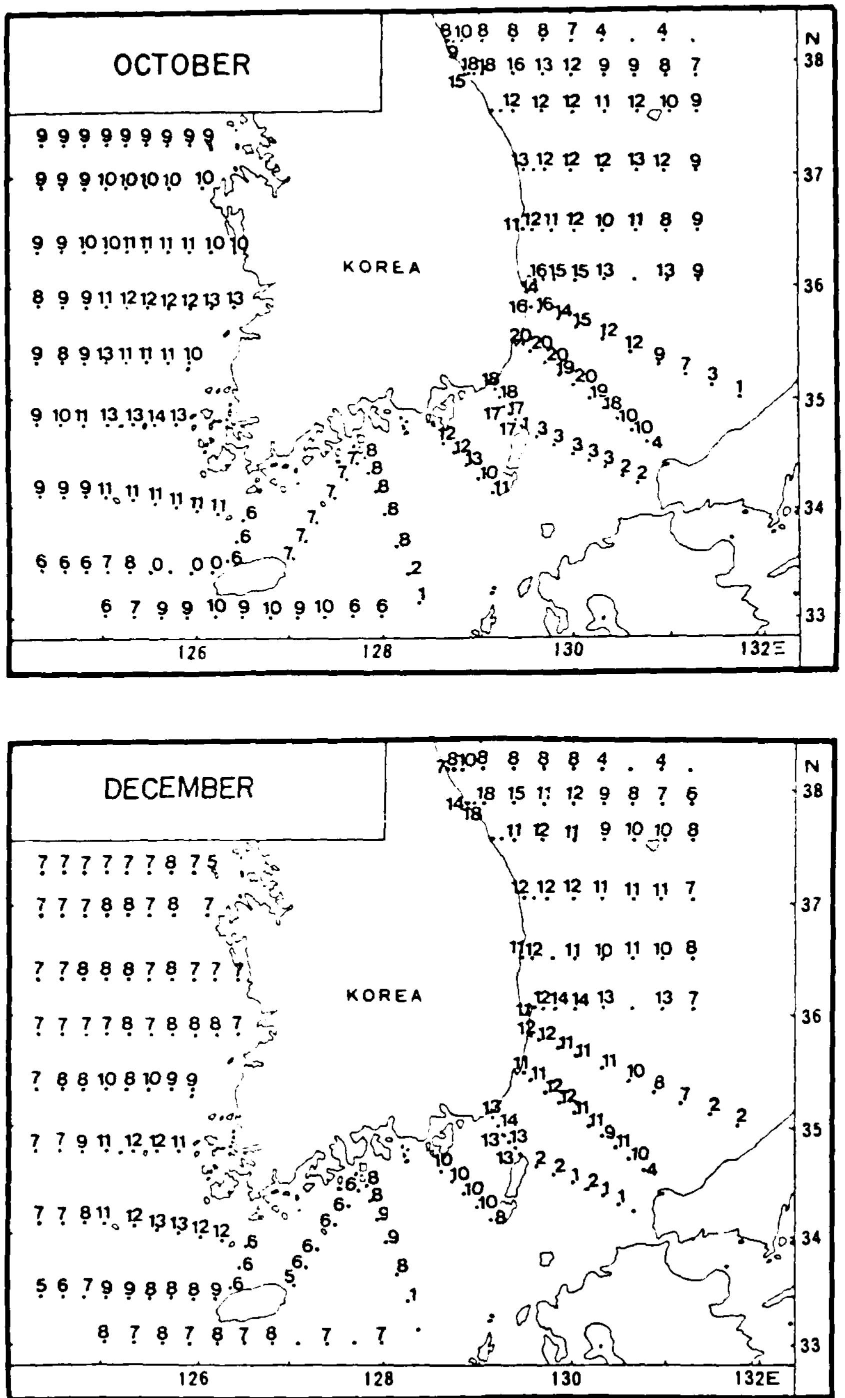
Figure 2-5.
Data volume at sectional serial stations around Korea (1961-75).





(Courtesy of KORDI)

Figure 2.5.
(Cont'd)
Data volume at sectional serial stations around
Korea (1961-75).



(Courtesy of KORDI)

Figure 2.5.
(Cont'd)
Data volume at sectional serial stations around Korea (1961-75).

Although the most recent tabulation of the NODC holdings of Japanese serial oceanographic data is not available, the holdings as of 1970 were reported to be 94,380 stations, the highest among all the foreign serial station data held at the NODC (JODC News, No. 3, 1972). This was almost 5 times the NODC holdings of the USSR data (20,386), almost 6 times those of the Norwegian data (16,836), and more than 7 times those of the UK data (13,075). The NODC holdings of the U.S. serial data were 59,732 at that time, approximately two thirds of the Japanese data.

Regarding the surface current data, the NODC's SCUDS (Surface Current Data System) file as of January, 1981, reportedly contained 5,106 Japanese GEK data (taken prior to 1974) and 85,243 Japanese ship-drift data. This may be compared to the holdings of UK ships-drift data of 10,245 and the French data of 3,895 (Insert to "User's Guide to NODC's Data Service, Feb., 1974," dated January 8, 1981).

NAVOCEANO

The NAVOCEANO maintains an unclassified data file which contains data collected from the NAVOCEANO survey ships plus data extracted from the files of the NODC and various DOD libraries. As of 1976, (Naval Oceanographic office Data Summary", TN3007-1-77, January, 1977), some data of interest to this study are identified in the NAVOCEANO file. Table 2-9 summarizes these holdings in 4 Marsden 10^{o}-square areas surrounding the sea straits under study. (For the exact location of the named 10^{o} squares, see Figure 2-3).

TABLE 2-9. Data holdings in the NAVOCEANO file for regions surrounding the sea straits, as of 1976.

PHYSICAL PARAMETER	DATA TYPE	FILE CODE	MARSDEN 10° SQUARE			
			131	132	166	167
MBT	Temperature vs. depth to maximum depth of 275 m.	34312	373	128	26	24
XBT	Temperature vs. depth, major amount to -456 m, substantial number to -760 m, and a few to -1,800 m.	3721	343	66	42	67
Climatology, including SST	Air temperature, seas, swell, winds, weather, SST.	34312	3,250	3,961	0	0
Surface Current	Multinational ship-drift data. Some surface current-meter and Japanese GEK data are included.	34312	218	191	56	17
Subsurface Current	Data collected with Richardson Geodyne-type meters in a taut-line bottom-anchored array.	34312	14	39	22	14
Subsurface Current	Data from open literature.	34312	118	99	55	25

Source: Wilkerson, J.C., 1977. Naval Oceanographic Office Data File Summary. NAVOCEANO TN 3007-1-77, 134 p.

3. DATA INVENTORY

3.1 Rationale

In 1978, the University of Virginia's Department of Environmental Sciences developed a coastal information and data referral system patterned largely after the then existing SHARP (Ships Analysis and Retrieval Program) system of the David Taylor Naval Ship Research and Development Center (DTNSRDC). Known initially as the "University of Virginia Information System" (UVAIS), it was subsequently transferred to the Naval Oceanographic Office's facilities at Bay St. Louis, Mississippi, effective March 1980. With the transfer, some necessary modifications were made to its format and system access routines, and the UVAIS was renamed "Coastal Environmental Reference Service" (CERS) to serve as a companion information referral system along with the existing "Oceanographic Environmental Reference System" (OERS).

At the onset of the present study, it was contemplated that a sea strait information referral system may be developed following the UVAIS configuration. However, it soon became apparent that sea strait data had some fundamental differences from the coastal processes data, particularly in terms of data acquisition procedures. The sea strait data is acquired through cruises, operated mostly from a ship, and consists of parameters which are essentially "oceanic" in nature and three-dimensional in spatial distribution. On the other hand, the coastal processes data generally occupies a point or a short linear segment along a coastline, has a unique emphasis on morphodynamic behaviors of the boundary and wave action, and is usually acquired from fixed-point measurements and observations, largely shore-based.

The "Oceanographic Environmental Reference System" (OERS) was much better suited to accomodate the data configuration of sea strait parameters. However, in this study, it was necessary to introduce a few modifications to incorporate sea strait data into the OERS in its existing form.

The OERS is designed to accomodate synoptic data. For this reason, the world ocean has been divided into broad regions much too large for the size of a sea strait. For instance, of a total of 133 water bodies of the world which have been given code designation in the OERS, only 21 are sea straits, channels, passages, and seaways. The only sea straits which have been identified with code in the general vicinity of this study are the Formosa Strait (Code 3F) and Tartar Strait (3D).

In the present study, the following convention was used to designate each of the sea straits of interest. The entire data inventory was divided into three regions adjacent to the Tsushima, the Tsugaru and the Soya Straits, and each was distinguished by assigning project code SEA STRAIT 1, SEA STRAIT 2, and SEA STRAIT 3, respectively. To further specify the identity of each sea strait, two adjacent ocean areas were entered to designate the associated General Ocean Areas. For instance, the general ocean areas for the Tsushima Strait are the East China Sea (Code 3E) and the Sea of Japan (3J), those for the Tsugaru Strait are the Sea of Japan (3J) and the North Pacific Ocean (3A), and those for the Soya Strait are the Sea of Japan (3J) and the Sea of Okhotsk (3Q). All the pairs of the adjacent ocean areas are mutually distinctive. Additionally, with the consent of the Naval Oceanographic Office, a new code designating the sea strait was introduced to add to the list of "Types of Marine Zones." This code is "15". A combination of these composite designations is sufficient to identify any of the three sea straits under study uniquely without altering the existing format of the OERS Cruise Data Inventory (see Table 3-1).

Another modification was aimed at maximizing the utility of the existing OERS Cruise Data Inventory format. The OERS allows a 600-character space to add comments on each data entry. This space was used in this study to describe:

- o Specific locality of the data.
- o Identity of a data report, if any, and the holding library in the U.S.
- o Summary of the data volume.

For instance, the comment on specific locality always mentions a sea strait by its common name (i.e., Tsushima, Tsugaru and Soya) and indicates whether the data was taken upstream, downstream, east, west, or in the channel of a particular strait. This is the only location in the Cruise Inventory Format where specific common name of a sea strait (instead of a code) is described. Comments on identity of data report include the title of the report, issue number, year of publication, and publishing agency. Comments on data content describe number of serial observational stations, BT stations and GEK stations. The comments also list holding libraries in the U.S.A.

Thus, a single query into the OERS Cruise Data Inventory would lead to information not only on how much, when, where, by whom and how the data was acquired, but also on the identity and whereabouts of appropriate data reports.

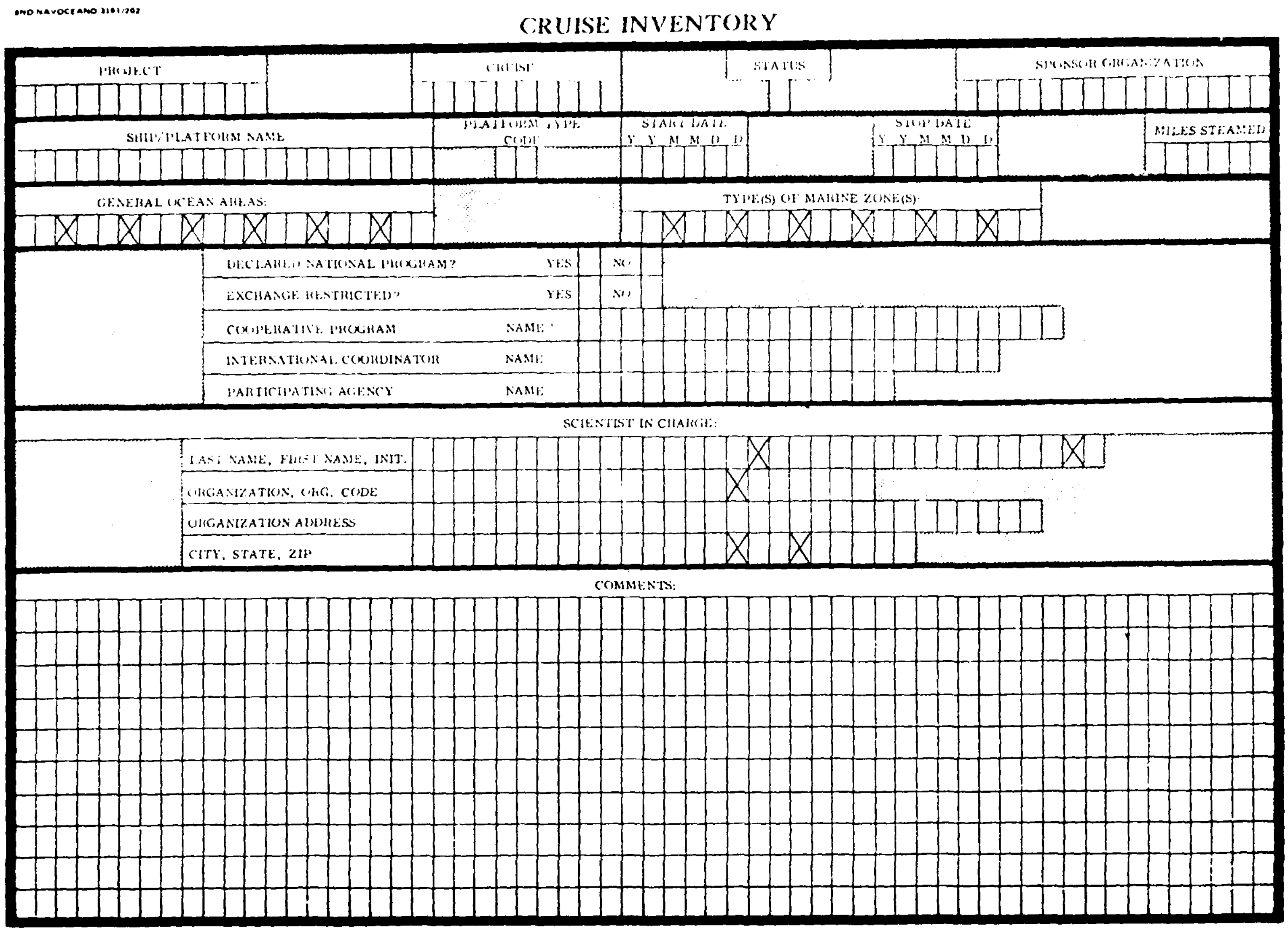
The OERS is designed to complete the information content with a dual data inventory, consisting of the Cruise Data Inventory and the Station Data Inventory (or the Underway Data Inventory for geology, geophysics, hydrographic measurements under way, etc.). In this study, the Station Data Inventory was not prepared for several apparent reasons. First, the expanded Cruise Data Inventory already provides a general configuration of data content which the Station Data Inventory is designed for. Second, the Japan Oceanographic Data Center (JODC) of the Japan Hydrographic Office has already embarked on a task of data archiving with the aim to consolidate the entire range of oceanographic data acquired by the Japanese and Korean sources. The JODC has so far advanced in this effort as to be able to provide vertical summaries and ocean current statistics as well as individual cruise data up to a quite recent point of time. This capability has been tested with the cooperation of the JODC as part of the efforts in the present study. Third, the present study was devoted to a limited objective of developing a referral system useful to investigators who are uninitiated to oceanographic data acquisition practices in the Far East.

3.2 Oceanographic Environmental Reference Service (OERS)

A good description of the OERS is given in NAVOCEANO's Instructions for OERS Reporting System." Figure 3-1 shows a Cruise Inventory reporting format (8ND NAVOCEANO 3161/202). A selected excerpt from "Instructions for OERS Reporting System" is presented as follows:

The Oceanographic Environmental Reference Service (OERS) is a computer-based reference system developed at the Naval Oceanographic Office and sponsored by Commander, Naval Oceanography Command. It was developed to compile an inventory of oceanographic data collected by, or of specific use to the Navy. It is one of several functional divisions of the Oceanographic Management Information System (OMIS). The OERS data base is implemented under a UNIVAC system software package known as DMS-1100.

In order to maintain currentness of the data base, an inventory reporting system has been devised. The basis of this system is three forms which will provide information in a format


8ND NAVOCEANO 3161/202

CRUISE INVENTORY

PROJECT | CRUISE | STATUS | SPONSOR ORGANIZATION

SHIP/PLATFORM NAME | PLATFORM TYPE CODE | START DATE Y Y M M D D | STOP DATE Y Y M M D D | MILES STEAMED

GENERAL OCEAN AREAS: | TYPE(S) OF MARINE ZONE(S):

DECLARED NATIONAL PROGRAM? YES NO

EXCHANGE RESTRICTED? YES NO

COOPERATIVE PROGRAM NAME

INTERNATIONAL COORDINATOR NAME

PARTICIPATING AGENCY NAME

SCIENTIST IN CHARGE:

LAST NAME, FIRST NAME, INIT.

ORGANIZATION, ORG. CODE

ORGANIZATION ADDRESS

CITY, STATE, ZIP

COMMENTS:

Figure 3-1. "Cruise Inventory" reporting format, 8ND NAVOCEANO 3161/202, for OERS (Oceanographic Environmental Reference Service).

which is quickly convertible to digital data. An attempt was made to minimize the effort necessary to complete the forms by arranging logically associated data items on separate forms.

The "Cruise Inventory"form (8ND NAVOCEANO 3161/202) provides for inclusion of information on the whole data collection effort while the two data inventory forms provide more detailed information about the environmental parameters observed during the cruise. A cruise is defined as any data collection activity - conducted ashore, afloat, underwater, or in the air - regardless of the type of platform employed. A shipboard cruise should be reported "port-to-port". For some activities this constitutes a cruise "leg". In such cases, identify the leg by appending "-1", "-2", etc. to the cruise identifier (e.g. 343606-1). The data dictionary for the Cruise Inventory form gives further explanation for each item of information solicited. If a larger comment section is required, continue on a plain sheet of paper and attach it to the form.

Each type of data collected or observed during the cruise will be reported on one of the two data inventory forms. Form 8ND NAVOCEANO 3161/203, titled "Station Data Inventory", is for recording information about data collected while the platform or sensor is in a fixed position relative to the horizontal datum. The "Underway Data Inventory" form (8ND NAVOCEANO 3161/201) will be used to report the data types listed under the "GU" group (geology, geophysics, and hydrography measurements underway), group "N" (navigation), and continuous observations such as "H01" (continuous temperature recording).

Specific entries into the OERS Cruise Inventory are annotated in "Instruction for OERS Reporting System" as follows:

Project: List the project name or identifier or the name of the sponsoring program.

Cruise: Cruise identifier as assigned by sponsoring agency.

Status: P - Planned cruise
C - Completed cruise

Sponsor Organization: Enter the name of the organization in charge of the data collection activity.

Ship/Platform Name: The name or official designation of the ship, plane or other survey platform used for this effort.

Platform type: Enter code from the following table.

01 - Research/Survey ship	08 - Submerged float (anchored)
02 - Other ship	09 - Submerged float (drifting)
03 - Satellite	10 - Fixed platform
04 - Balloon	11 - Fixed coastal station
05 - Fixed-wing aircraft	12 - Drifting ice
06 - Anchored buoy	13 - Submersible
07 - Drifting buoy	14 - Other
	15 - Rotary-wing aircraft

Start Date: First day of cruise. Format YYMMDD.

Stop Date: Last day of cruise. Format YYMMDD.

Miles: Miles steamed or flown during cruise.

General Ocean Area: Enter the code(s) for the water bodies in which the cruise occurred, using the definitions supplied in Defense Intelligence Agency Manual No. 65-18.

Marine Zones: Enter the code(s) for the marine zones covered during this cruise from the following table:

01 - River mouth, estuary	07 - Continental shelf
02 - Zone connected with the sea (harbors, lagoons, etc.)	08 - Continental margin
03 - Intertidal or near-shore zone	09 - Major ridges, fractures
04 - Coastal zone	10 - Seamounts, guyots, and atolls
05 - Offshore zone in inland sea	11 - Abyssal plain
06 - Open Sea	12 - Troughs
	13 - Great Lakes (US & Canada)
	14 - Lakes (other)
	15 - Sea Strait

Declared National Program? Check yes or no according to whether the activity is or is not part of a "declared national program".

Exchange Restricted? Check yes if any part of the data is subject to exchange restrictions.

Co-operative Program: If the cruise is part of a co-operative program, name the program.

International Coordinator: If the cruise is part of an internationally coordinated program, list the coordinating agency or individual.

Participating Agency: If another agency funds, participates in, or assists in the cruise, enter the name of that agency.

Scientist in Charge:

- Last name, first name, middle initial.
- Organization: e.g. NAVOCEANO
- Organization Code: (if used within organization).
- Organization Address: Street address, PO box, etc.
- City, State, and Zip: No explanation necessary.

Comments: Add as many 60-character lines of comment as necessary to describe lost time, unusual weather, equipment failures, etc.

In the OERS, in order to permit a wide spectrum of users to be able to access the data base independently, an interactive retrieval program is provided to allow the formulation of queries by providing answers to programed prompts. A detailed description on the use of the OERS is given in: "The Oceanographic Environmental Reference Service Retrieval Program Guide", by Richard L. Rein, NAVOCEANO RP-31, February 1981 (32 p.).

3.3 Guidelines for Users

The OERS provides "reference information" on data rather than the data per se. Standard data base elements in the OERS cruise inventory include identification of sea strait (called "Project"), cruise number code, sponsoring organization, ship's name, data collection dates, identification of general ocean area, type(s) of marine zone, coordinating agencies, data exchange availability, scientist(s) in charge and his address. However, in order to enhance the information content in the data base, we have also added an annotation describing specific localities of cruise, published oceanographic data reports and the holding libraries, amount of cruise stations by parameter, and other necessary comments. Thus, our enhanced cruise inventory contains not only information on data collection activity but also on data volume and whereabouts of appropriate data reports.

The user can access the OERS data base either by cruise, parameter, water body, or global coordinates (WMO area identifier). In order to further assist the user in accessing the data base, this report contains additional material for orientation:

- o A complete summary of plotted cruise tracks by the three most important data collecting agencies in Japan (Hydrographic Office, Fisheries Agency, and Meteorological Agency), is provided in Appendices 1, 2, and 3. A potential user may first thumb through these cruise tracks to gain a swift preliminary assessment of the existing data volume in a specific area of interest.

- o Statistical summary of cruise stations by area, parameter and agency is provided in Chapter 3.4: "Overview of OERS Cruise Inventory on Japanese Sea Straits."

- o Major data collectors in both Japan and Korea, along with their geographical jurisdictions, survey ships and data volume, are described. (See Chapter 1.3: "Principal Data Collectors" and Chapter 1.4: "Tide and Tidal Currents").

- o A detailed chronology of principal oceanographic events relating to oceanographic data collection practices in Japan and Korea, including institutional evolutions and major oceanographic programs, is presented. (See Chapter 2.1: "Historical Perspective").

- o Recent patterns and trends in the data collecting practices in Japan and Korea are discussed in the report. (See Chapter 2.2: "Patterns and Trends").

- o Current status of data archiving effort is reviewed, with special emphasis on the Japan Oceanographic Data Center, in Chapter 2.3: "Status of Data Archiving".

- o A descriptive oceanography relating to the Tsushima, the Tsugaru and the Soya Straits is presented to identify the current state of knowledge. (See Chapter 3: "Descriptive Oceanography").

- o An annotated bibliography is prepared to outline representative research efforts on the three sea strait regions. (See Chapter 4: "Annotated Bibliography").

The following entry conventions have been used:

"<u>PROJECT</u>":

The entry is SEA STRAIT 1, SEA STRAIT 2, or SEA STRAIT 3, respectively, for the Tsushima, the Tsugaru, and the Soya Straits (see Table 3-1). For the boundary of each of these sea strait regions, see:

Figure 1-2 (A): Boundary of the Tsushima Strait region.

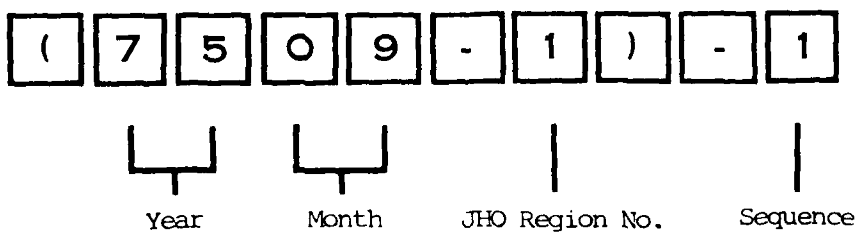
Figure 1-2 (B): Boundary of the Tsugaru Strait region.

Figure 1-2 (C): Boundary of the Soya Strait region.

"<u>CRUISE</u>":

Appropriate cruise codes were employed so as to include the identity of data collector, the year and month of data collection, and the sequence, if any, of data collection runs whenever it was necessary to distinguish cruises which were conducted within the same general time period by the same agency.

The cruise code for the Japan Hydrographic Office follows a format:



This particular example represents a cruise carried out by the JHO Region No. 1 (Head Office at Otaru, Hokkaido) in September 1975. Since two cruises were carried out by this region office during this month (though with different vessels), the sequence

number "1" is assigned to distinguish them from each other. Since the JHO Region No. 1 is based in Hokkaido, the cruise code as shown would imply that the data collection was concerned with either the Tsugaru or the Soya Straits. For the office location, geographical jurisdictions and typical cruise tracks of various JHO region offices, see:

Table 1-2: "Principal agencies engaged in serial oceanographic observations".

Figure 1-3: "Location map".

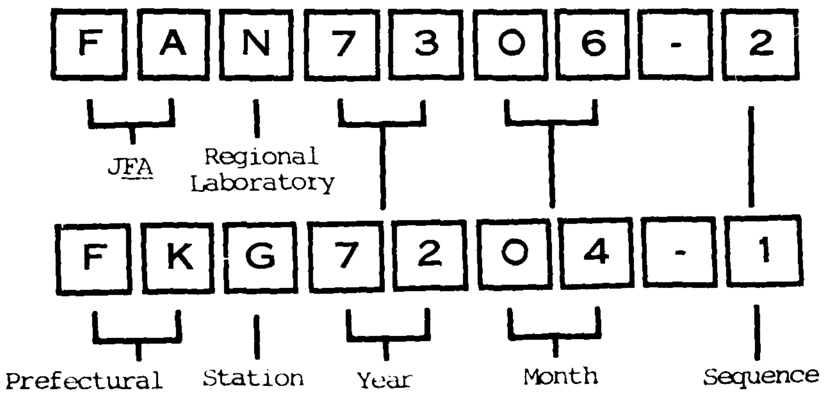
Figure 1-4. "Typical cruise tracks for serial observations by Japan Hydrographic Office (JHO)".

Figure 1-5. "Typical cruise tracks for serial observations by Japan Fisheries Agency (JFA) and its affiliated prefectural stations".

Figure 1-6: "Typical cruise tracks for serial observations by Japan Meteorological Agency (JMA)".

Figure 1-7: "Fixed lines for serial observations by Fisheries Research and Development Agency and Hydrographic Office in Korea".

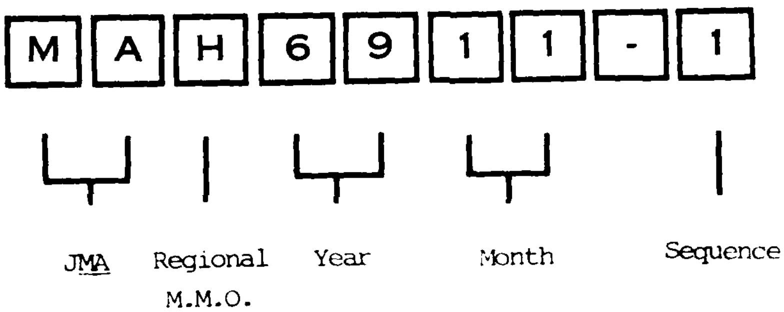
The cruise code for the Japan Fisheries Agency and its affiliated prefectural fisheries experiment stations follow a dual format:



The first format, FA-series, designates the Japan Fisheries Agency and/or one of its Regional Fisheries Research Laboratories. The second format, FK-series, designates a prefectural Fisheries Experiment Station which usually functions in close coordination with a JFA's Regional Fisheries Research Laboratory. The coding conventions employed in this study are summaried in:

> Table 1-2: "Principal agencies engaged in serial oceanographic observations".

The cruise code for the Japan Meteorological Agency follows a format:



The heading "MA" denotes Meteorological Agency, and the third alphabetical character denotes one of the JMA's regional Marine Meteorological Observatories (H for Hokkaido M.M.O., K for Kobe M.M.O., N for Nagasaki M.M.O, M for Maizuru M.M.O.) or the JMA Headquarters (Q for Headquarters). The ensuing numerical codes denote the year (2 digits), the month (2 digits), and a sequence number (1 digit) whenever more than one cruises were made during the same month by the same agency.

"STATUS":

All the entries are completed ("C") cruises.

"SPONSORING ORGANIZATION":

The entry is headed by "JHO", "JFA", or "JMA" depending upon the identity of the data collector's head agency followed by the respective region identity such as:

JHO: REGION 1 through REGION 11.

JFA: HOKKAIDO, TOHOKU, TOKAI, NANKAI, SEIKAI, NIHONKAI or NAIKAI.

JMA: HAKODATE, KOBE, NAGASAKI, MAIZURU, or HQS (headquarters in Tokyo).

For prefectural fisheries experiment stations, only the name of the prefecture appears (with no agency heading), such as:

AOMORI KEN*
SAGA KEN*
FUKUOKA KEN*
YAMAGUCHI KEN*
SHIMANE KEN*

(*)KEN = prefecture

HOKKAIDO WAKKAN (i.e., Wakkanai)
HOKKAIDO HAKODA (i.e., Hakodate)
HOKKAIDO CHUO (i.e., Central)
HOKKAIDO ABASHIR(i.e., Abashiri)

"SHIP/PLATFORM NAME":

The same Japanese and Korean names could be spelled in more than one way. Namely, "SHUMPU MARU" could also be spelled "SYUMPU MARU". The names used should be construed as phonetic. "MARU" is a common Japanese designation for a ship, which is occasionally missing for some ships. The Korean counterpart is "HO".

"PLATFORM TYPE":

The platform type is exclusively "research/survey ship" (code 01).

"START DATE":

The start date listed in the data report may either mean the departure date for a voyage or the actual start date of survey. In either case, since the cruise usually takes place adjacent to the home port, there are only one to a few days of difference between the two.

"STOP DATE":

Likewise, the end date could either mean the date of return to a home port or the actual ending date of survey under way.

"MILES STEAMED":

This entry is usually left unfilled, as the cruise tracks are generally fixed over many years and an approximate estimation can be readily made from the published cruise track charts (Appendices I, II and III).

"GENERAL OCEAN AREAS":

There are four "general ocean areas" in the study area:

East China Sea	: 3E
Sea of Japan	: 3J
Sea of Okhotsk	: 3Q
North Pacific Ocean	: 3A

For immediate upstream and downstream sides and inside the channel of a sea strait, both of the adjacent ocean areas are named. For an area far upstream or far downstream, only one of the ocean areas is named.

"TYPE(S) OF MARINE ZONE(S)":

Usually, the cruise relating to a sea strait takes place on the continental shelf (07), but it could also be on an open sea (06) at the same time, depending upon the location of a ship during a cruise. No special effort was made to distinguish the two, and the entry was usually named "open sea" (06). An additional code "15" was introduced, with the approval of the Naval Oceanographic Office, to designate a sea strait.

"DECLARED NATIONAL PROGRAM?":

The number of cruises which are designated as "Declared National Program" (DNP) has been increasing in recent years. The DNP data is eventually forwarded to the World Data Center, but some uncertain amount of delay is usually expected between the time of data acquisition and the time of data delivery. Although the JODC annually has been publishing in its supplemental issues of JODC News the DNP-designated cruises (since 1972), this entry has been left unfilled for the time being.

"EXCHANGE RESTRICTED?":

The entry is "NO".

"COOPERATIVE PROGRAM"

This means "international" cooperation. The entry has been left unfilled, pending more detailed investigation.

"INTERNATIONAL COORDINATOR"

This entry has been left unfilled, pending more detailed investigation.

"PARTICIPATING AGENCY":

This entry has been left unfilled, pending more detailed investigation.

"SCIENTISTS IN CHARGE":

The name of a scientist in charge has been entered whenever it was available in the data reports. When a scientist in charge was not known, the entry only gave the organization and its address. For the JHO data, only one name was used consistently: Mr. Shozo Yoshida, associate director of the JODC at the JHO Headquarters in Tokyo. It is advised to contact Mr. Yoshida whenever a clarification is sought on Japanese oceanographic data irrespective of collecting agencies:

Mr. Shozo Yoshida
Japan Oceanographic Data Center
Hydrographic Office, Maritime
Safety Agency (Kaijo Hoan-cho)
5-3-1 Tsukiji, Chuo-ku, 104
Tokyo, Japan
Telephone: Tokyo (03) 541-3811
Telex: (03) 252-2452
Telefax: (03) 545-2885

Regarding Korean data, an inquiry may be directed to Mr. Suk-Woo Lee, current President of the Oceanological Society of Korea:

Mr. Suk-Woo Lee
Korean Ocean Science and Engineering Corp.
214-5, Huam-Dong, Yongsan-ku,
Seoul, Korea
Telephone: Seoul 793-1684
Cable Address: KOSECORP, SEOUL

"COMMENTS":

This entry space is organized into four parts:

Coverage: Specific location of the cruise relative to the sea strait. The entry may state such as "Upstream of Tsushima Strait", "Downstream of Tsushima Strait", "Far Upstream of Tsushima Strait", etc. For the west coast of Hokkaido, which would either belong to a downstream region of the Tsushima Warm Current beyond the Tsugaru Strait or an upstream region of the Soya Strait, the entry is usually "West of Hokkaido".

Data Report: The entry gives the name of the data report, its issue and year of publication, publisher, and the holding libraries in the U.S., usually the Scripps Institution Library at La Jolla, California, and the Woodshole Oceanographic Institution Library at Woodshole, Massachusettes.

Data Content: Number of occupied stations are given for serial observations, BT stations and GEK stations.

Comments: Any additional appropriate comment, as necessary.

3.4 Overview of OERS Cruise Inventory on Japanese Sea Straits

Table 3-2 summarizes the number of cruises which were entered into the OERS Cruise Inventory file in this study, shown by the sea strait region, agency and year. A total of 2,025 entries were accomplished in this study, excluding the cruises performed by the Korean agencies. The cruises performed by the Japanese agencies prior to about 1960 exist in scattered local agencies and could not be fully consolidated. However, the number of annual cruises prior to 1960 was generally few, and the number of cruises missing for this period probably did not exceed a few hundred.

Table 3-3 summarizes the data volume which were entered into the OERS Cruise Inventory file. Several interesting facts emerge from these statistics:

- The Tsushima Strait enjoyed the intensive surveys by the Japanese agencies, followed fairly closely by the Tsugaru Strait. The Soya Strait is the least surveyed of the three sea straits.

- In the Tsushima Strait, there exists an extensive amount of serial observations due mainly to the heavy contributions by the five prefectural experiment stations facing the strait which traditionally maintain a strong interest in fishery oceanography. In contrast to the Fisheries Agency, the JHO and the JMA mainly resort to GEK and BT measurements in the Tsushima Strait.

- In the Tsugaru Strait, the Fisheries Agency again is the most important contributor of serial observations; the JHO conducted the most amount of GEK measurements; and the JMA contributed the most amount of BT measurements. The JHO's emphasis on GEK and the JMA's emphasis on BT measurements in the Tsugaru Strait both outweighed those in the Tsushima Strait.

- In the Soya Strait, the JFA's serial observations and the JHO's GEK measurements constitute a dominant part of the overall data population.

- The JFA has not begun to use GEK in its oceanography operations.

All the three straits and all the three Japanese agencies combined, the amount of data which were entered in the OERS Cruise Inventory file thus far totaled 30,690 serial stations, 14,881 BT casts, and 25,027 GEK measurements.

TABLE 3-1. Code designation of the three sea strait regions adjacent to Japan in the OERS Cruise Data Inventory.

SEA STRAIT REGION	OERS CRUISE DATA INVENTORY CODING		
	PROJECT	GENERAL OCEAN AREA	TYPE OF MARINE ZONE
Tsushima	SEA STRAIT 1	3E, 3J	15
Tsugaru	SEA STRAIT 2	3J, 3A	15
Soya	SEA STRAIT 3	3J, 3Q	15

Note:

3E	East China Sea
3J	Sea of Japan
3A	North Pacific Ocean
3Q	Sea of Okhotsk
15	Newly introduced code, designating a sea strait under the marine zone category.

TABLE 3-2. Summary of cruises compiled into OERS Cruise Inventory file.

SEA STRAIT	YEAR	NUMBER OF CRUISES		
		JHO	JFA	JMA
TSUSHIMA	1951	–	7	–
	52	–	7	–
	53	–	–	–
	54	–	–	–
	55	–	–	–
	56	7	–	–
	57	6	–	–
	58	7	–	5
	59	4	–	3
	60	4	–	4
	61	6	–	5
	62	4	–	5
	63	3	47	6
	64	5	62	7
	65	5	61	6
	66	3	67	3
	67	4	63	6
	68	6	65	2
	69	9	67	10
	70	9	65	2
	71	3	36	6
	72	4	66	7
	73	10	55	4
	74	14	48	6
	75	5	40	3
	76	9	–	–
	77	–	–	2
	78	–	–	3
SUBTOTAL		127	756	95

TABLE 3-2. Summary of cruises compiled into OERS Cruise Inventory file. (Cont'd)

SEA STRAIT	YEAR	NUMBER OF CRUISES		
		JHO	JFA	JMA
TSUGARU	1951	–	1	–
	52	–	–	–
	53	–	–	–
	54	–	–	–
	55	–	–	–
	56	10	–	–
	57	9	–	–
	58	15	–	4
	59	10	–	2
	60	5	–	4
	61	5	–	6
	62	9	–	7
	63	2	25	4
	64	4	31	3
	65	7	37	4
	66	11	34	3
	67	6	33	6
	68	3	37	5
	69	9	39	7
	70	9	41	9
	71	14	13	2
	72	6	52	7
	73	12	56	4
	74	11	54	7
	75	16	43	2
	76	13	–	–
	77	–	–	4
SUBTOTAL		183	496	90

TABLE 3-2. Summary of cruises compiled into OERS Cruise Inventory file. (Cont'd)

SEA STRAIT	YEAR	NUMBER OF CRUISES		
		JHO	JFA	JMA
SOYA	1951	–	2	–
	52	–	–	–
	53	–	–	–
	54	–	–	–
	55	–	–	–
	56	5	–	–
	57	8	–	–
	58	8	–	–
	59	7	–	–
	60	2	–	–
	61	1	–	–
	62	1	–	–
	63	1	9	–
	64	2	8	–
	65	1	7	–
	66	1	8	–
	67	4	7	1
	68	6	8	–
	69	4	13	–
	70	3	10	–
	71	8	4	–
	72	14	18	–
	73	23	12	–
	74	16	3	–
	75	26	9	–
	76	21	–	–
SUBTOTAL		159	118	1

TABLE 3-3. Data volume in OFRS cruise inventory file for sea straits around Japan

SEA STRAIT	AGENCY	DATA STATIONS			DATA YEARS
		SERIAL	BT	GEK	
Tsushima	JHO	456	1,702	5,573	1956-76
	JFA	13,920	757	0	1951,52,63-75
	JMA	2,475	2,573	7,098	1958-78
	Subtotal	16,851	6,032	12,671	
Tsugaru	JHO	497	1,148	6,202	1956-76
	JFA	8,729	1,545	0	1951,52,63-75
	JMA	1,736	4,995	3,594	1958-78
	Subtotal	10,962	7,688	9,796	
Soya	JHO	243	524	2,551	1956-76
	JFA	2,630	628	0	1951,52,63-75
	JMA	4	9	9	1958-78
	Subtotal	2,877	1,161	2,560	
Total	JHO	1,196	3,374	14,326	
	JFA	25,279	2,930	0	
	JMA	4,215	8,577	10,701	
Grand Total		30,690	14,881	25,027	

4. DESCRIPTIVE OCEANOGRAPHY

4.1 Tsushima Strait

Overview of Problems

One of the most interesting and yet unresolved problems relating to the Tsushima Warm Current is: where and how the Tsushima Warm Current does originate. A prevailing view in the past has been that a current branches out from the Kuroshio at some location southwest of Yakushima (south of Kyushu), which then moves northward as the Tsushima Warm Current along the west coast of Kyushu. Numerous attempts to establish an evidence linking the Kuroshio and the Tsushima Warm Current have been unsuccessful (Nagata, 1980). Buoys released in the area west of Kyushu where the presence of the northbound Tsushima Warm Current is suspected have tended to either reveal local stagnation with insignificant current velocities or southward excursion. A new concept which has appeared recently (Minato and Kimura, 1980) hypothesizes that a current is driven into the Tsushima Strait by a pressure gradient generated between the Tsushima Strait and the Tsugaru Strait by the western boundary current of the subtropical Gyre in the North Pacific. Since the western boundary current is not directly contiguous to the Tsushima Strait, it appears that the oceanographic and meteorological conditions in the intervening region between the boundary current (the Kuroshio) and the Tsushima Strait, as well as the pressure gradient between the Tsushima and Tsugaru Straits, should play a role in influencing the volume transport and its fluctuations.

Another interesting problem relating to the Tsushima Strait is the behavior of the Tsushima Warm Current extension inside of the Tsushima Strait in the Sea of Japan. Numerous studies have been published regarding whether the extension forms two or three branches, or it rather forms a meandering system, or both. Although the recent trend of thought appears to favor the possibility of "meander", oceanographic data stations are still too coarse to ascertain the exact situation. In the view of the present writer, the behavior of the Tsushima Warm Current extension in the Sea of Japan would depend largely upon the Japan Sea Polar Front, although this possibility has not been stressed in the literature. The Japan Sea Polar Front maintains conspicuous presence in the Sea of Japan dividing the cold water of the northern Sea of Japan from the warm water on the south which is connected to the East China Sea and the

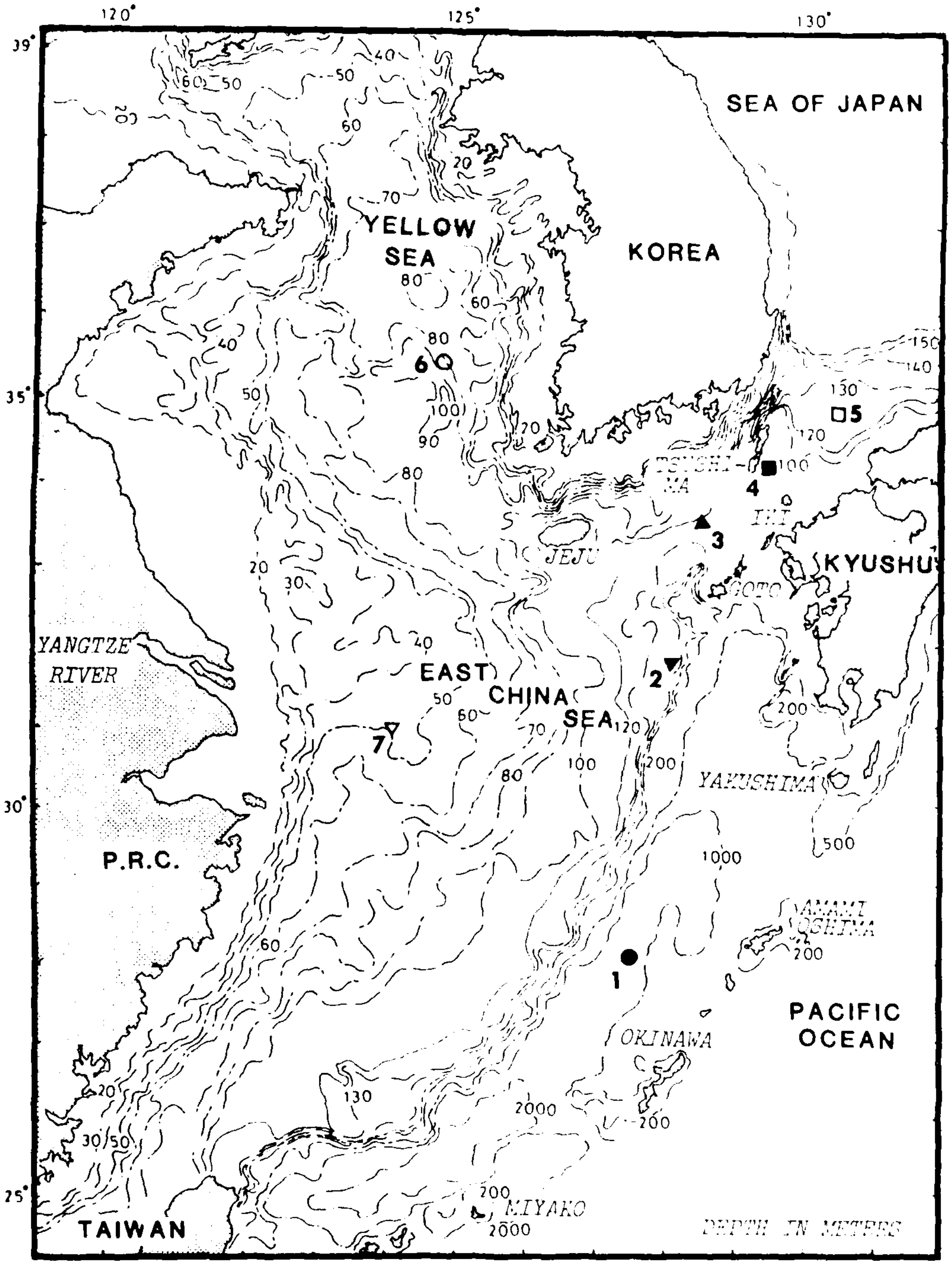
Pacific Ocean. The dominant presence of the Japan Sea Polar Front is exemplified by its width as large as 200 km or more, which is indicative of the intensity of mixing along its front, and by the length which often stretches over the entire east-west width of the Sea of Japan.

Upstream Region

Among the topical subjects in the upstream region of the Tsushima Strait are: (1) the formation of characteristic water mass of the Tsushima Warm Current, and (2) the branching of the Tsushima Warm Current from the Kuroshio.

There have been numerous studies on the upstream region of the Tsushima Strait. (See, for example, Seikai Fisheries Research Laboratory, 1973.) A large amount of oceanographic data were collected along the Kuroshio region between Taiwan and Yakushima (See Figure 4-1) during the CSK (Cooperative Study of Kuroshio) program, 1965 - 77 (JODC, 1981). Recently, during 1972 - 1975, Japan conducted a comprehensive investigation of the East China Sea under a joint program among the Japan Hydrographic Office, the Fisheries Agency, and the Japan Meteorological Agency under the financial management of the Science and Technology Agency (S.T.A., 1977). Research/survey vessels of the JFA Seikai Fisheries Research Laboratory, the prefectural fisheries experiment stations of Nagasaki, Saga and Fukuoka Prefectures, the JHO Region No. 7 (based at Kitakyushu) and No. 10 (based at Kagoshima), and the JMA Nagasaki Marine Meteorological Observatory, routinely cruise the upstream region of the Tsushima Strait, including the East China Sea close to the Yangtze River estuaries and part of the Yellow Sea.

Figure 4-2 shows a schematic rendition of major water mass distributions and currents (K.F.P.D.C., 1976). The Kuroshio, moving in the northeast direction over the continental slope of the East China Sea, exhibits a strong (1-3 knot), narrow (a core region with over 1.0 knot only about 30 n. miles wide) current, and mixes with waters of the East China Sea. It is believed that the Kuroshio yields a branch bound for the Tsushima Strait as it turns east toward the Pacific Ocean at a point about 100 n. miles west of Yakushima. The branch then moves northward on the west side of the Goto Retto (Goto Islands or Archepelago) while continuously mixing with the East China Sea water and, depending upon the season, partly with the Yellow Sea water. Upon reaching a point south of Jeju Island, this branch is believed to bifurcate into two currents: the Yellow Sea Warm Current which veers north-west toward the west coast of Jeju and Korean Peninsula, and the



(Courtesy of Seikai, R.F.L.)

Figure 4-1. Bathymetry in the upstream region of Tsushima Strait.

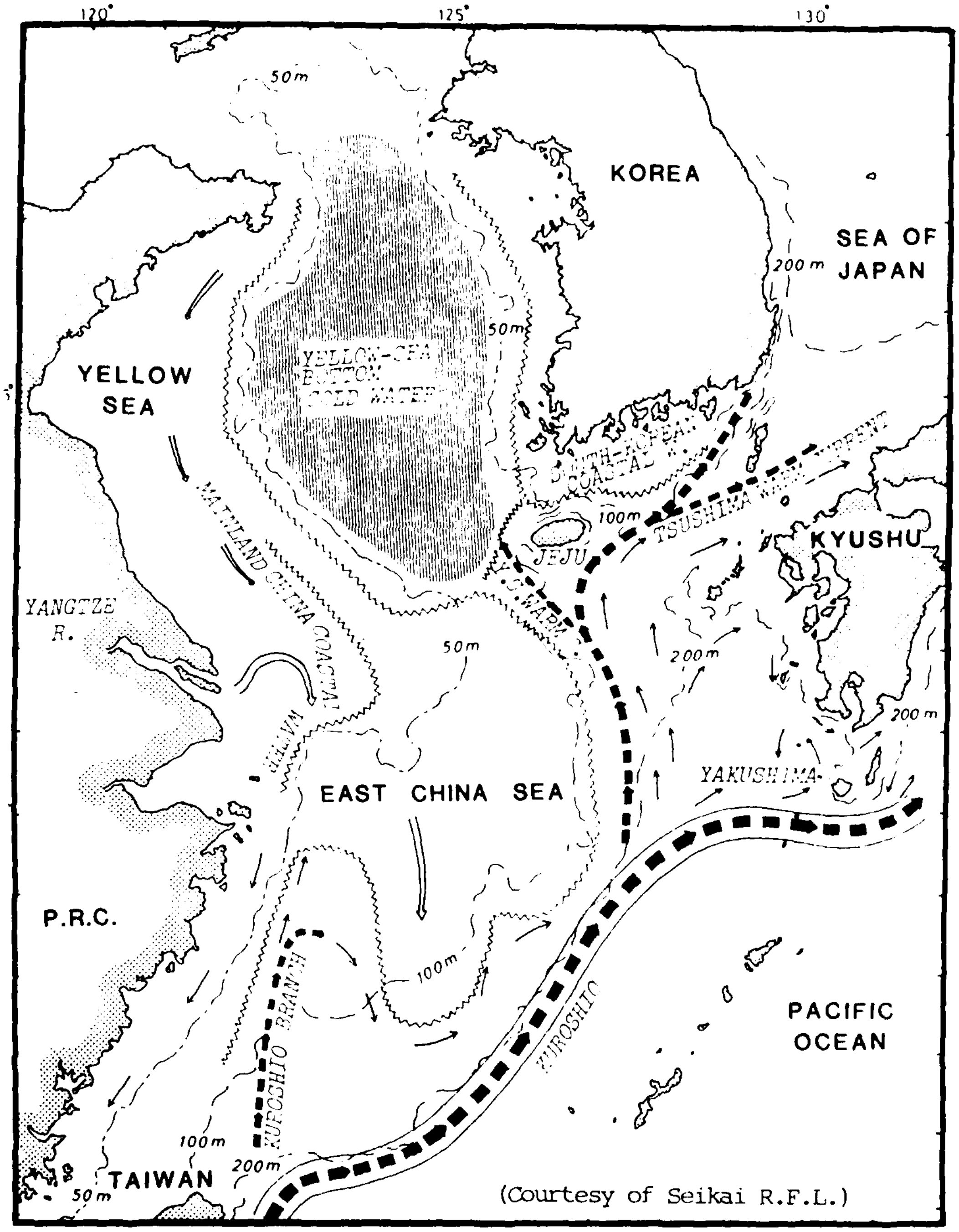


Figure 4-2. Schematic distributions of characteristic water masses and currents.

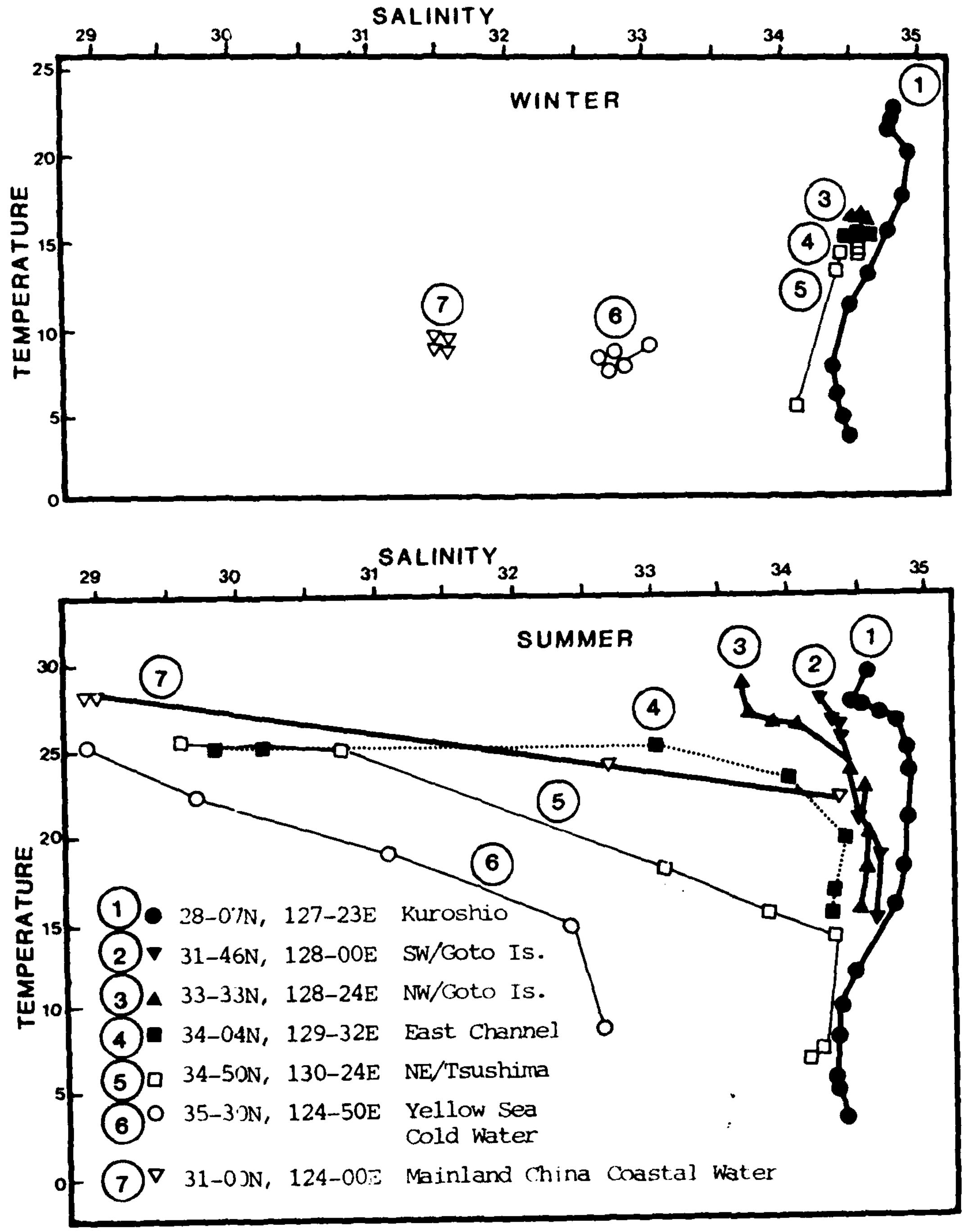


Figure 4-3. T-S diagrams for typical water masses upstream of Tsushima Strait. (Courtesy of Seikai R.F.L.)

Tsushima Warm Current which veers eastward bound for the East and West Channels of Tsushima Strait. As it approaches and subsequently enters the strait, the Tsushima Warm Current again mixes with coastal waters on both of its flanks with the South Korean Coastal Water and the Western and Northern Kyushu Coastal Water.

Thus, in the course of a journey from west of Yakushima to the strait, the characteristic water of the Tsushima Warm Current is formed as a result of mixing between the oceanic water of the Kuroshio and at least three water bodies of distinctly coastal origin: Mainland China Coastal Water, South Korean Coastal Water, and the Western and Northern Kyushu Coastal Water. Because these interacting water masses are highly contrasting in density, the formation of fronts and rips (or shiome in Japanese) has been well recognized in the mixing zones (see Figure 4-2). Since the distribution and characteristics of these coastal waters are highly seasonal, the water mass composition of the Tsushima Warm Current fluctuates considerably by the season.

Figure 4-3 shows T-S properties of water masses along the upstream path of the Tsushima Warm Current. The points are numbered sequentially in the current direction, as shown in Figures 4-1 and 4-2. Notice that the Kuroshio, the original water of the Tsushima Warm Current, is characterized by higher temperature and higher salinity than any other water masses in the region. In winter, both temperature and salinity drop slightly below 20°C and 34.6 PPT, respectively, at the surface, but exhibit little seasonal change below a 200-m depth.

The other extreme is the Mainland China Coastal Water which exhibits both temperature and salinity lower than any other waters in the region. Namely, at Position 7 (31-00N, 124-00E), where a depth is about 50 meters, temperature and salinity are around 9°C and 32.3 PPT, respectively, from surface to bottom in winter. In summer, the surface salinity at this location falls to as low as 29.0 PPT, while the surface temperature climbs to about 26°C.

In winter, surface temperature of the upstream Tsushima Warm Current falls distinctly as it approaches the strait, say to 17°C at SW/Goto, 14°C at NW/Goto, and 13-14°C in the strait, but without so much change in salinity (i.e., from above 34.6 PPT to about 34.3 PPT). In summer, there is a more pronounced drop in salinity than in temperature on the surface, as there is a greater degree of encroachment of the low-salinity coastal waters toward the side of the Tsushima Warm Current. Since the mixing

is confined to the surface layer, which also is heated seasonally, a stratification is well developed in the Tsushima Warm Current during this season

The South Korean Coastal Water exhibits higher salinity than the Mainland China Coastal Water both in winter and summer. The South Korean Coastal Water, when well developed in winter and during the monsoon season in early summer, expands into the West Channel, thereby pushing the axis of the Tsushima Warm Current toward the east against the coast of Kyushu. Figure 4-4 shows the fluctuation of the South Korean coastal front by season during 1969 (Gong, 1971). Temperature and salinity fronts generally coincided in winter as the sharp front became stabilized in the West Channel from fall to winter, whereas they did not necessarily coincide in summer when the front expanded as far as the East Channel.

Strong influence of the continental coastal waters on the upstream portion of the Tsushima Warm Current coupled with the influence of the annual fluctuation of the Kuroshio which would affect the intensity of mixing and entrainment along the boundary with the East China Sea water may thus be considered to account for the two well-known characteristics of this current: its annual variability as a result of the inherent fluctuations and cycles of the runoff from the major rivers, and the vertical mixing which is typically limited to the upper layer due to the shallow depth of the coastal waters (to about 200 m below the surface).

The fronts and rips (or Shiome) which are recognized along the Tsushima Warm Current in its upstream region (Figure 4-2) are known to be typically limited to the surface layer. Figure 4-5, showing cumulative monthly anomalies of water temperature at different layers in the East Channel of the Tsushima Strait, demonstrates the extreme annual variability of the Tsushima Warm Current. One notices a sustained 14-year increase in temperature between 1948 and 1962, followed by the abrupt commencement of a steep down-turn in the ensuing decade. The presence of an average 6-year cycle is also readily recognized.

Table 4-1 summarizes characteristic temperature maxima and minima for typical water masses in the upstream region of the Tsushima Strait.

Figure 4-6 shows seasonal sea surface temperature variability from the values in the upstream region of the Tsushima Strait.

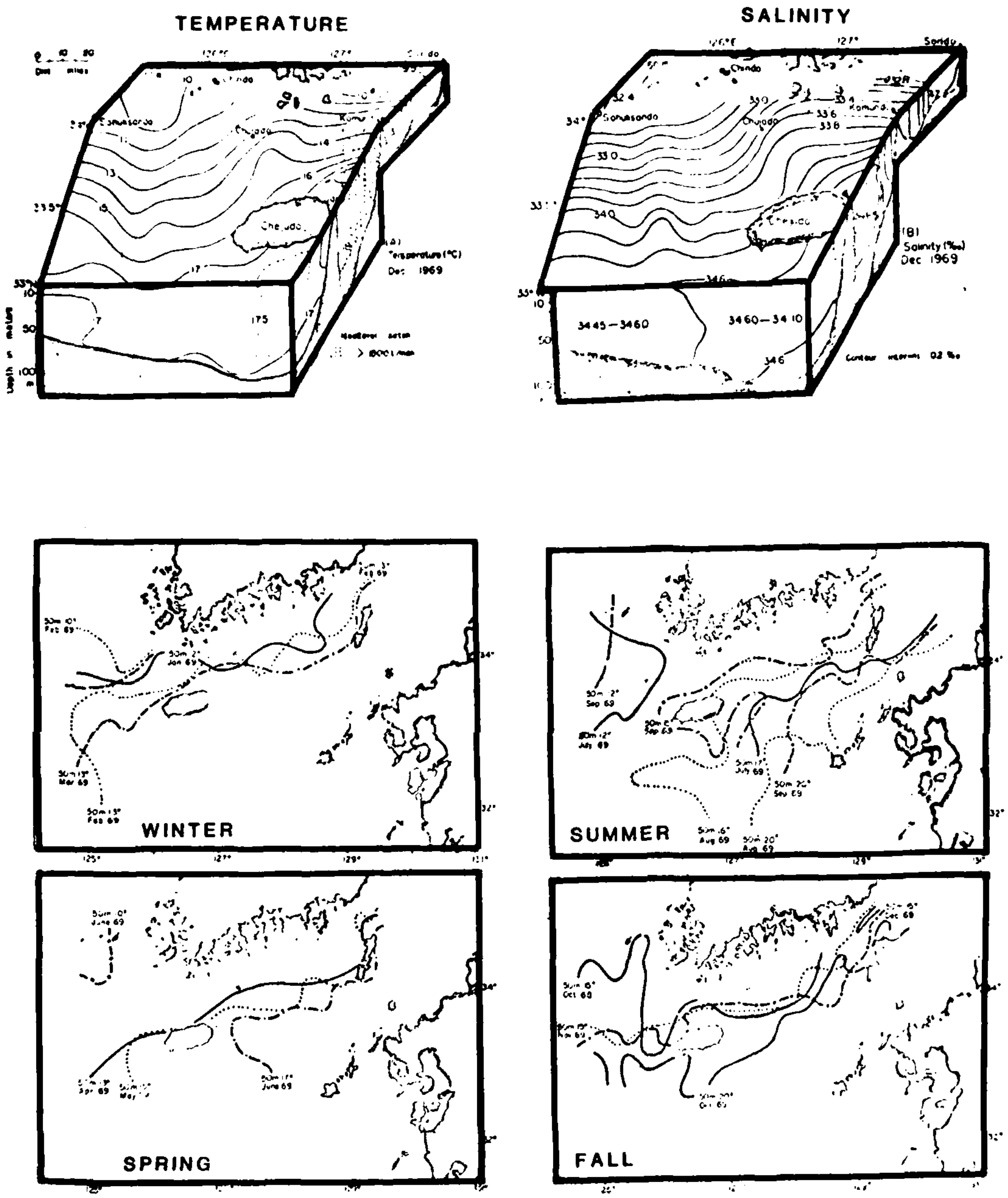


Figure 4-4. Seasonal distribution of South Korean coastal front. (Gong, 1971)

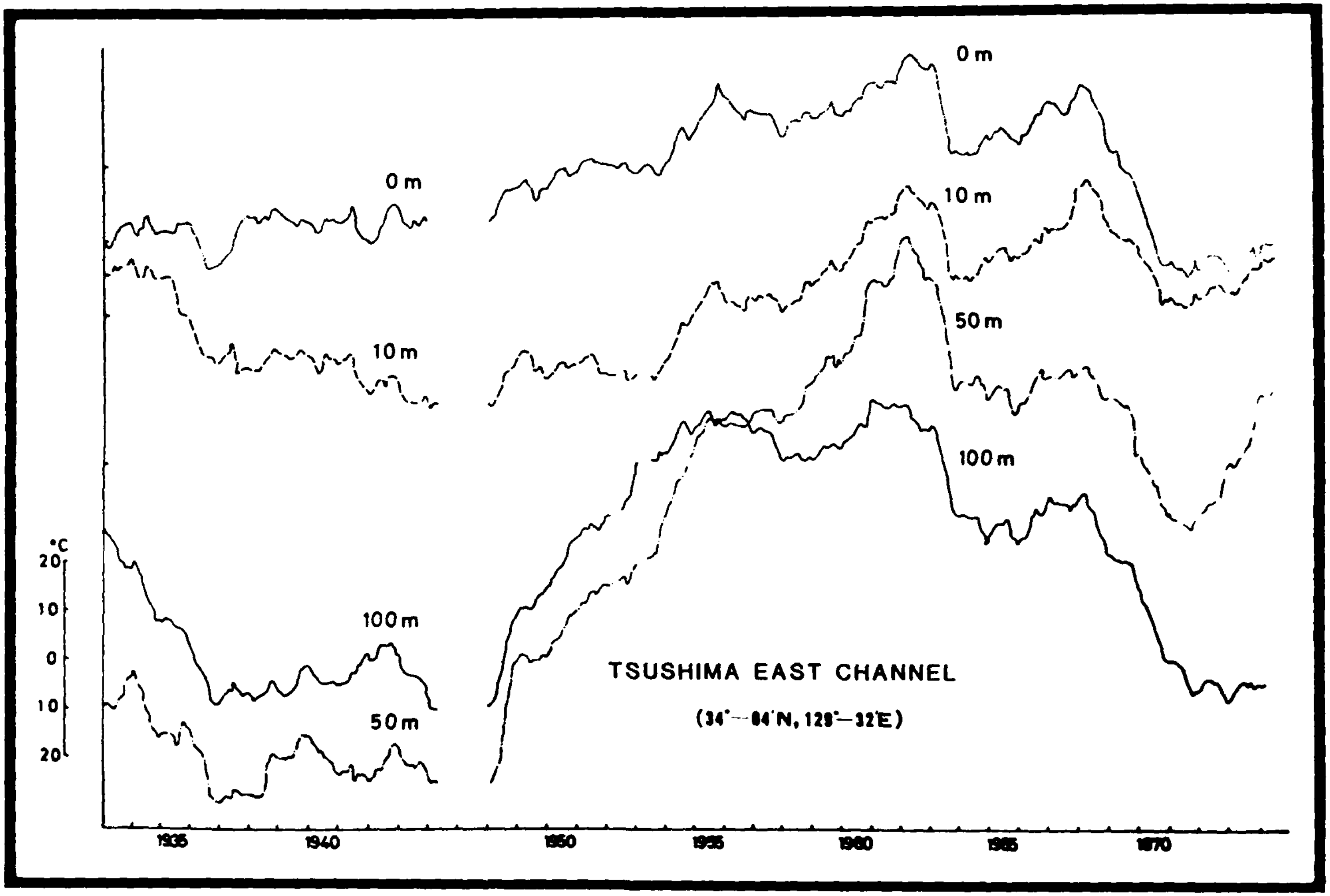


Figure 4-5. Cumulative monthly temperature anomalies in the East Channel of the Tsushima Strait (Seikai R.F.L., 1973).

TABLE 4-1. Summary of characteristic water masses in the upstream region of Tsushima Strait.

WATER MASS LOCATION	LAT. N	LONG. E	MAX. TEMP. MONTH	°C	MIN. TEMP. MONTH	°C	ANNUAL MEAN	ANNUAL RANGE
Kuroshio (South)	25	123	Jul., mid	29.6	Feb., early	23.0	26.4	6.6
Kuroshio (North)	28	127	Aug., all	29.3	Feb., early & mid	21.5	25.4	7.8
Tsushima Warm Current (South)	32	128	Aug., mid	27.0	Feb., late	7.5	18.3	19.5
Tsushima Warm Current (North)	33.5	128.5	Aug., early & mid	28.1	Mar., early	14.9	20.6	13.2
Socotra Rock	32	125	Aug., mid	27.2	Mar., mid	9.2	17.4	18.0
Mainland China Coastal (North)	31	124	Aug., mid	28.0	Feb., late-Mar., early	10.3	18.8	17.7
Mainland China Coastal (South)	29	123	Aug., early & mid	28.2	Feb., late-Mar., early	13.1	20.6	15.1
Yellow Sea Cold Water	34	123	Aug., early & mid	25.9	Mar., late	8.1	14.9	17.8

(Source: K.F.P.D.C., 1976)

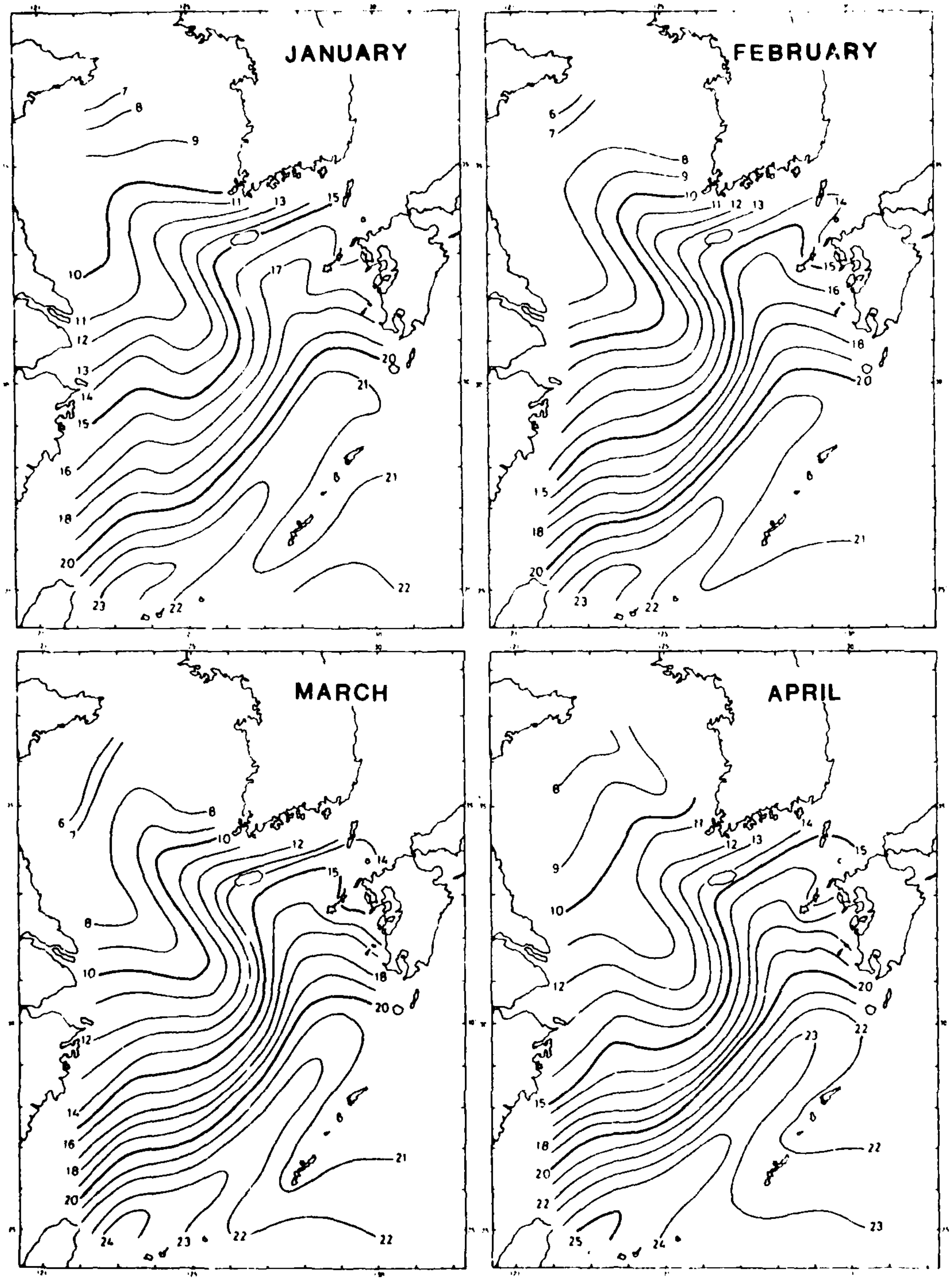


Figure 4-6. Monthly sea surface temperature distributions in the upstream region of the Tsushima Strait. (Seikai R.F.L., 1973)

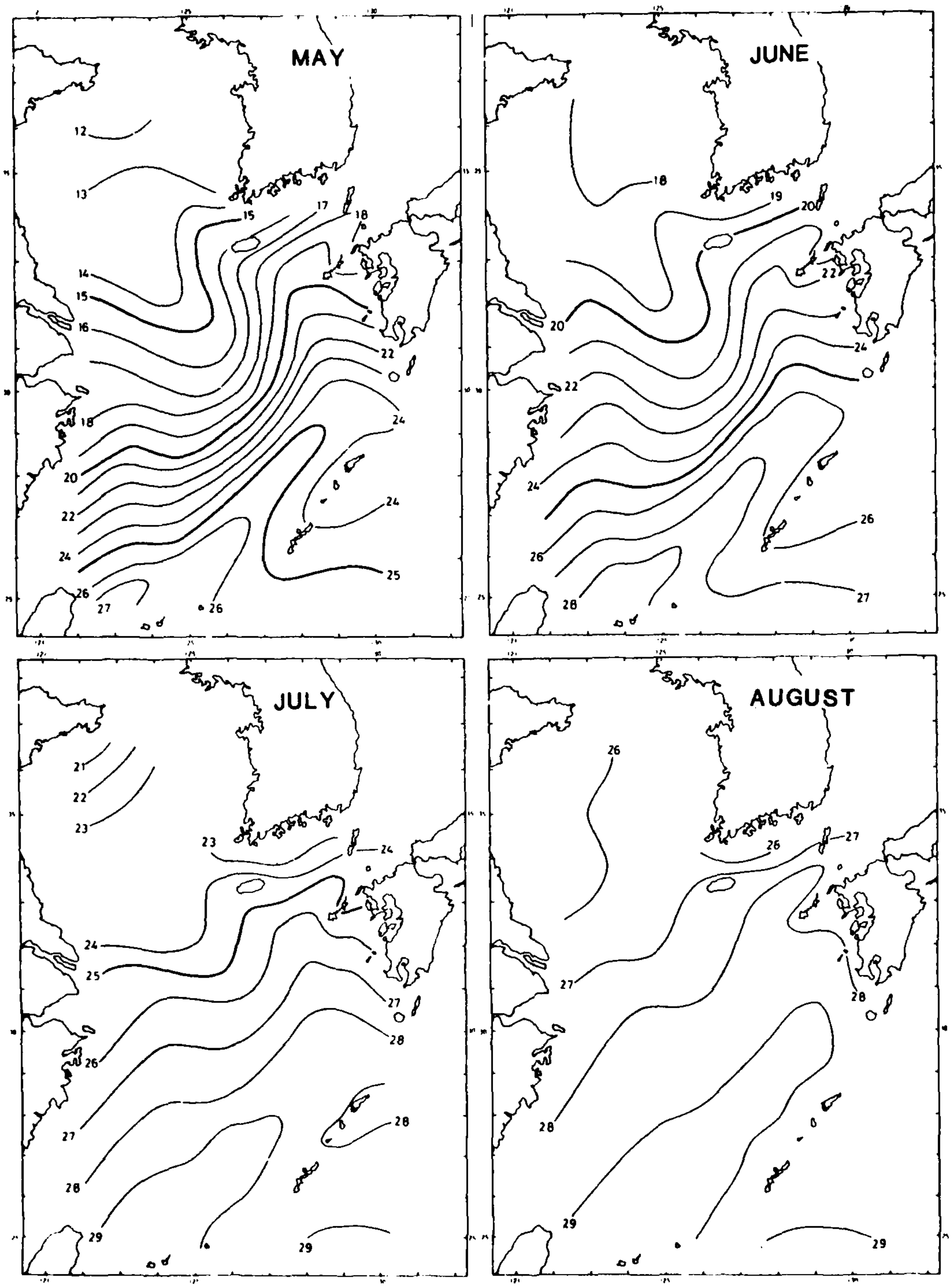


Figure 4-6. (Cont'd)

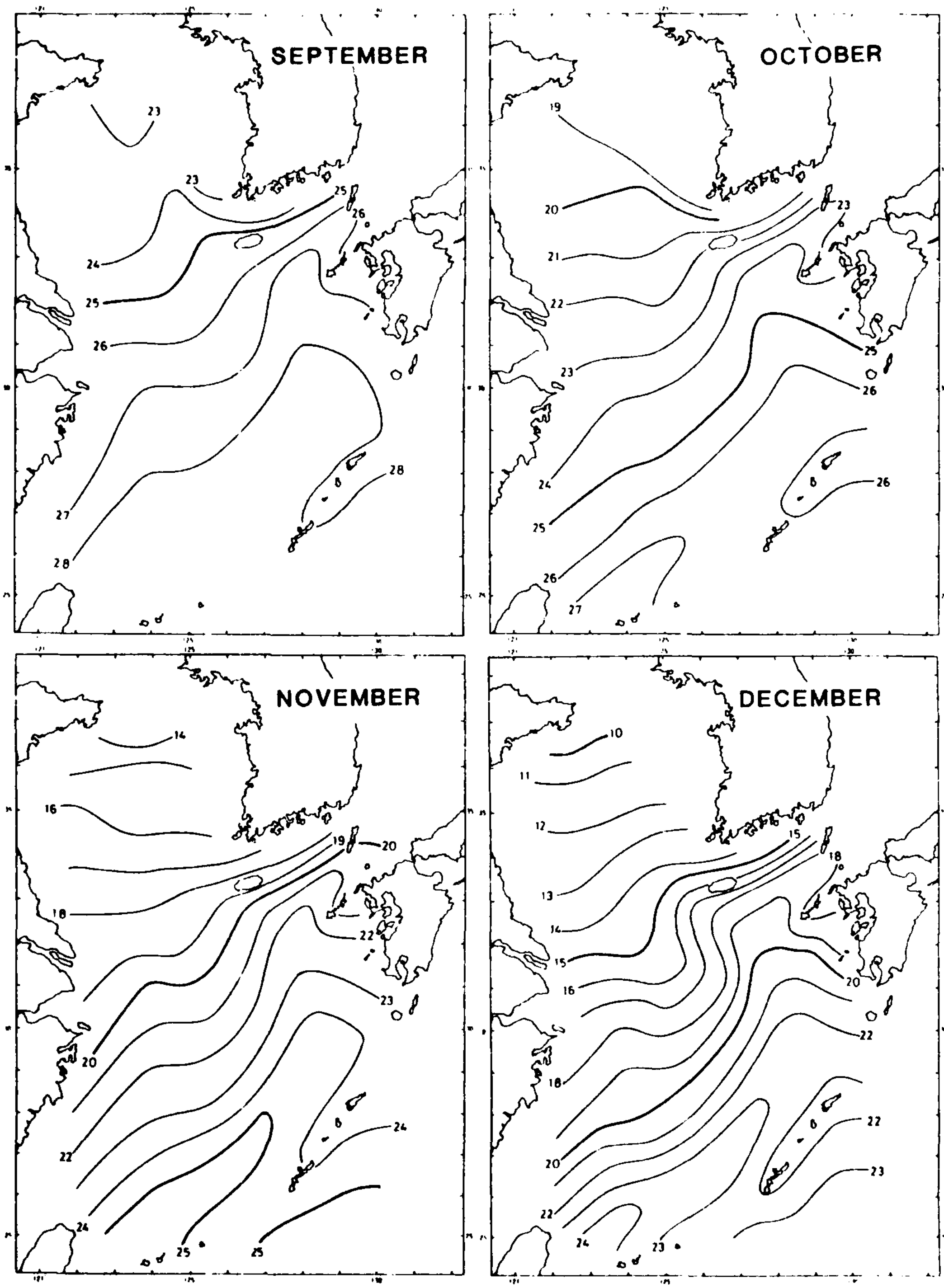


Figure 4-6 (Cont'd)

Figure 4-7 presents a schematic view of three suspected branching patterns west of Yakushima. In the vicinity of the suspected branching, the current patterns are reported to be highly complex, and no clear evidence of distinct branching has been uncovered (Nagata, 1980).

Figure 4-8 shows typical seasonal current patterns in this area, determined mostly from GEK measurements and partly from dynamic calculations, in which the velocity is shown in knot. In an area west of Yakushima where the northward-flowing Tsushima Warm Current is broadly defined, the northward volume transport has been calculated to be from 5 to 15 Sv (as compared to 30 - 50 Sv for the Kuroshio, southeast of Yakushima). Volume transport through the Tsushima Strait is reported to be 1.6 - 1.9 Sv in the East Channel and 1.7 - 1.9 Sv in the West Channel (Yi, 1966).

The current regime in the upstream region of the Tsushima Strait are rendered further complex by a strong influence of tidal current (see Figure 4-9). Whereas the velocity in the Tsushima Warm Current is rated at 0.5 - 1 knot in its upstream region, the tidal current in the shallow continental shelf of the East China Sea ranges between 0.8 and 3.3 knots at peak phases (K.F.P.D.C., 1976), oriented mostly in the direction of the major axis (NW-SW) of the East China Sea/Yellow Sea basin. Figure 4-10 shows bottom currents from fixed measurements, indicating the possible combined influence of both ocean and tidal currents.

A comprehensive predictive computation of tide and tidal current has been performed recently by Choi (1980). The computation extends to an entrance area of the Tsushima Strait. An example of his results is shown under Chapter 4: Annotated Bibliography, <u>Tsushima Strait</u>.

A somewhat contrasting view has been advanced recently regarding the driving force for the inflow into the Tsushima Strait. Although this new approach does not necessarily reject the conventional notion on the branching of the Tsushima Current from the Kuroshio at its origin, it hypothesizes that the inflow is caused by the pressure difference between the Tsushima Strait and the Tsugaru Strait along the western boundary of the subtropical gyre (Minato and Kimura, 1980). These investigators demonstrated, by solving a steady linearized vorticity equation on a Beta plane with two openings (sea straits) on the western boundary, that the boundary current will indeed penetrate into a marginal sea from the southern opening and exit through the northern opening, driven

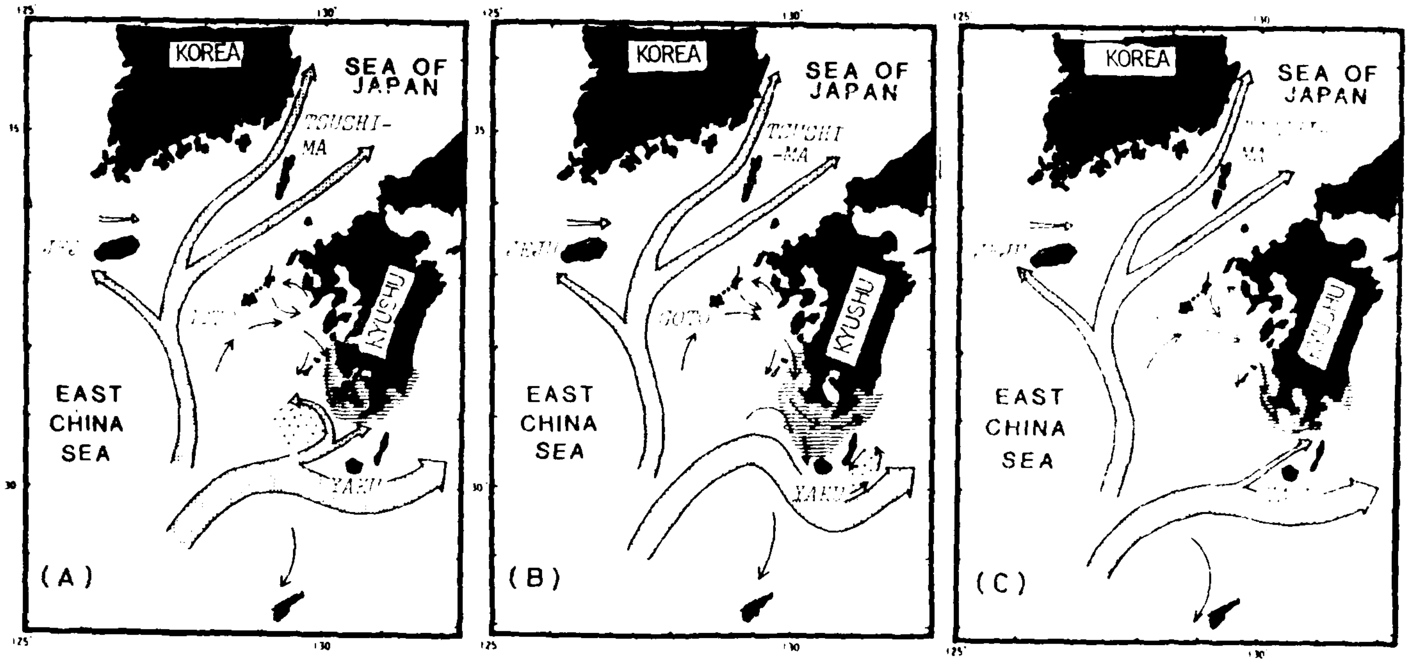


Figure 4-7. Suspected branching patterns of Kuroshio near Yakushima. (Seikai R.F.L., 1973)

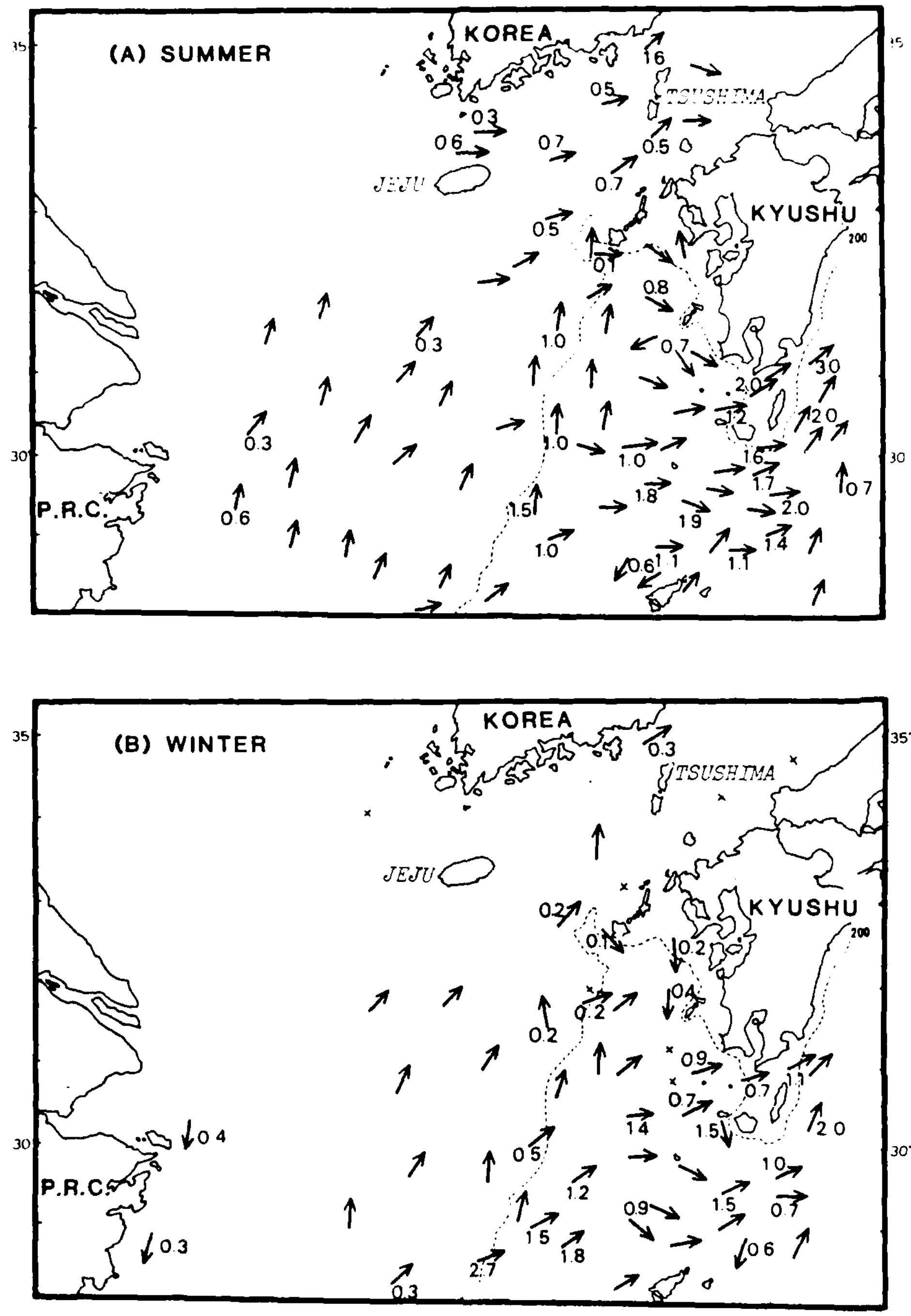


Figure 4-8. Seasonal surface current patterns in the upstream region of Tsushima Strait. (Seikai R.F.L., 1973

MAXIMUM FLOOD CURRENT

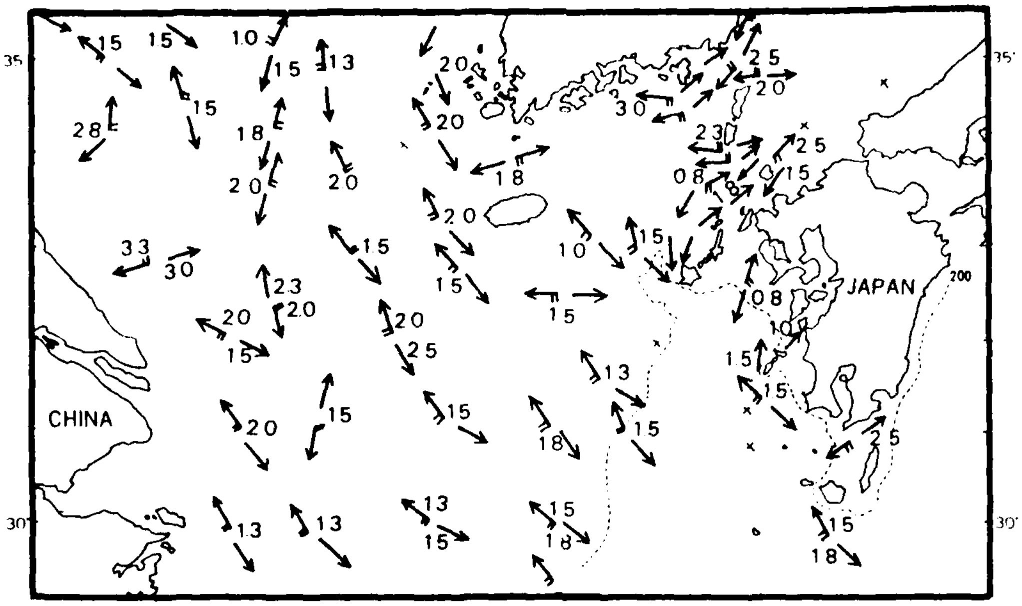


Figure 4-9. Maximum flood currents at Spring. (Seikai R.F.L., 1973)
(Seikai R.F.L., 1973)

BOTTOM CURRENT

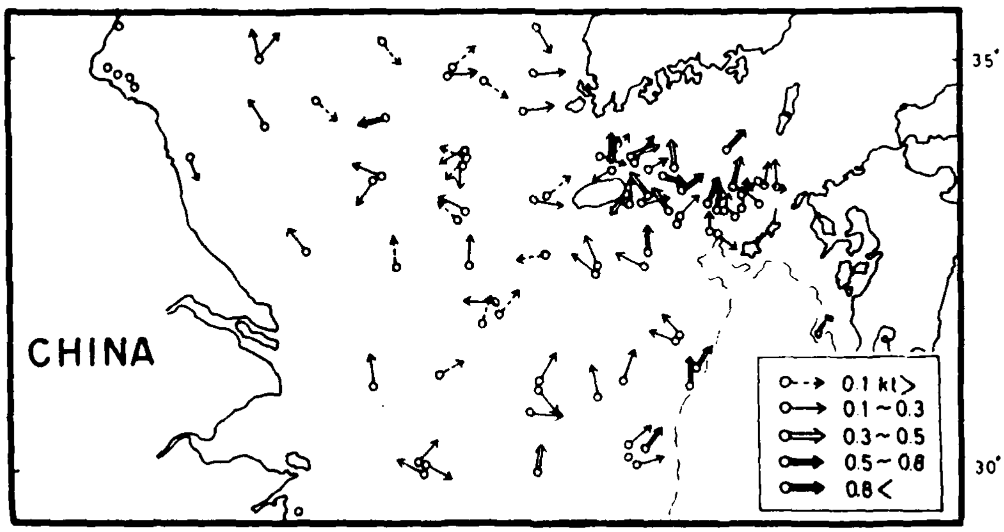


Figure 4-10. Annual mean non-tidal currents at bottom.
(Seikai R.F.L., 1973)

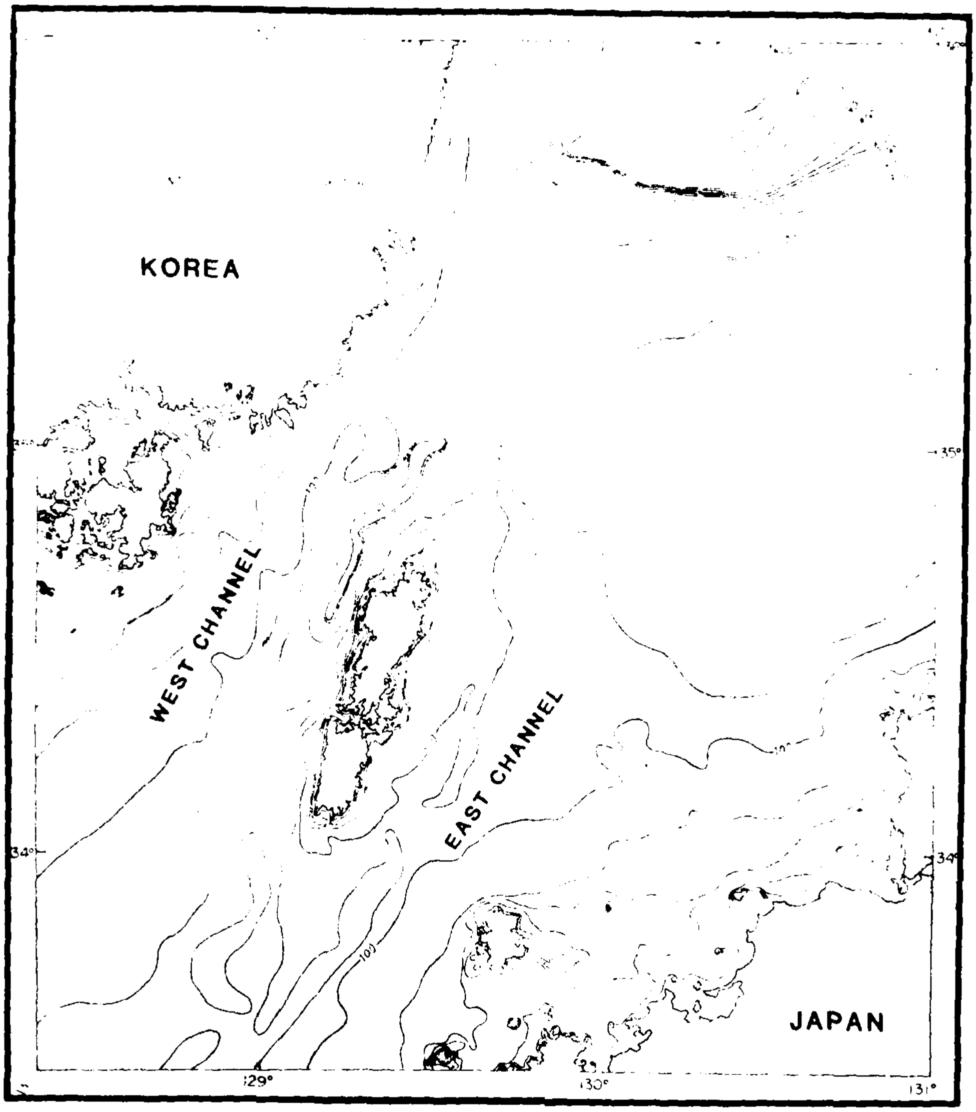
by the pressure gradient forming between the two openings along the boundary current. By implications, the result further stresses that the Tsushima Warm Current is sensitively subjected to oceanic influences of the spatial and temporal scales comparable to those of the Kuroshio.

Channel Region

Figure 4-11 shows the bathymetry of the Tsushima Strait. The bottom topography of the Tsushima Strait is essentially a continuation of the continental shelf of the East China Sea. It consists of a relatively flat sea bed with an average depth of about 100 meters, its monotoneity interrupted only by: (1) the presence of the Tsushima Island approximately in the middle of the Strait, (2) very irregular coastlines both on the Korean and Japanese coasts flanking the north and south sides of the Strait, and (3) a local depression about 200 meters deep on the West Channel. The bottom of the West Channel is more steeply sloped against the Korean coast because of this depression. On the Japan Sea side of the Strait, there is a very broad shallow bed to the northeast of the East Channel, whereas the West Channel continues for about 110 km north of the Tsushima Island where it encounters a steep slope descending to the abyss of the Sea of Japan. The Strait is about 50 km wide at its narrowest width in the West Channel between Busan and Sasuna, and about 47 km wide in the East Channel between Southern Tsushima Island and Iki Island. Measured between Ulsan and Kawajiri Misaki, the Strait is 90 km wide. A major river in this region is the Nakdong River of Korea which empties at a point only about 10 km west of Busan.

Among the topical subjects relating to the Tsushima Strait Channel region are: (1) volume transport, (2) mixing at the coastal front, and (3) dynamics of currents. One of the earliest estimates (Miyazaki, 1952) placed the volume transport through the Tsushima Strait at 0.3 - 3 Sv, variable with one order of magnitude. Moriyasu (1972) estimated it to be about 1 Sv. Given the extreme dependence of the Tsushima Warm Current on the dynamics of various water masses in its upstream regions, a high degree of variability in the volume transport through the strait both of seasonal and secular nature should be expected.

Thus far, the study by Yi (1966) probably sheds the most comprehensive light on this subject. Over the entire width of about 110 n. miles along Line 208 (between Ulgi of Korea and Kawajiri Misaki of Japan), he performed a geostrophic computation



(Lim & Chang, 1969)

Figure 4-11. Bathymetric map of Tsushima Strait.

(Figures 4-12, 4-13). On a seasonal basis, the northward transport increased rapidly from about 0.6 Sv in May to about 2.0 Sv in July. It remained high around 2.0 - 2.2 Sv during the ensuing five months to November, before dropping rapidly to about 0.6 Sv by January. During a four-month period from January to April, the transport remained low between about 0.6 and 0.4 Sv. During this low-transport period, there was also an outflow at about 0.2 Sv, whereas an outflow was virtually nil during the peak inflow season July-November. Thus, the volume transport varied seasonally by a range of about 2 Sv within the year.

Reviewing the transport data 1932-1941, Yi (1966) finds that annual mean values of net volume transport varied from a high of 1.3 Sv in 1935 to a low of 0.8 Sv in 1939 (Figure 4-13). In terms of northward transport, the variation was between a high of 2.7 Sv in 1932, 1936 and 1940 to a low of less than 0.4 Sv in 1934 and 1939. He points out a cyclic behavior of mean annual transport with an average periodicity of about 4 years. The investigator further ascertains that in light of the anomalous behavior of the Kuroshio which began in 1934 and the coincident decrease in volume transport through the Tsushima Strait as well as the formation of a well-developed bottom countercurrent which occurred along the East Coast of Korea in the same year, fluctuations in volume transport through the Tsushima Strait may have been closely related to the secular variations of the Kuroshio, the Oyashio, and the North Korea Cold Current.

Yi (1967) was also among the first to investigate the sea level variations with special reference to the current in the vicinity of the Tsushima Strait. He performed analysis of the monthly mean sea level data between around 1962 and 1966 at Ullungdo, Mukho, Ulsan, Pusan (or Busan), Chinhae, Yosu, Cheju (or Jeju), Mokpo and Inchon. The variations in monthly mean sea level were related mainly to steric and atmospheric pressure effects. The steric effect was most pronounced on the east coast facing the Sea of Japan and the south coast facing the Tsushima Strait, particularly at Pusan. Additional causes were river runoff on the west coast, and possibly the fluctuation of oceanic currents along the east and south coasts. The monthly mean sea levels were high in summer-fall and low in winter-spring, with a range of 20 - 50 cm.

Recently, precision measurements of currents with moored arrays have been performed in the Tsushima Strait. Burns (1975) analyzed six current meter records from the East and West Channels

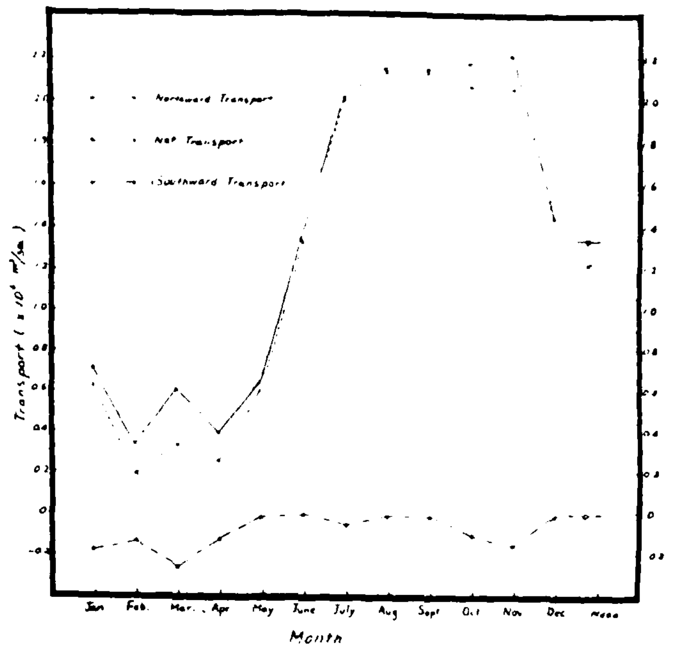


Figure 4-12. Monthly volume transport (Yi, 1966).

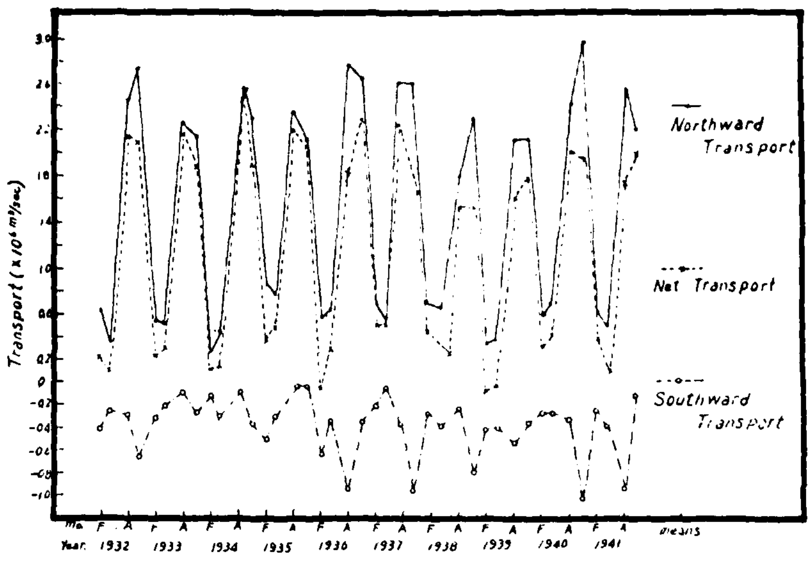


Figure 4-13. Annual volume transport (Yi, 1966).

TABLE 4-2(A). HARMONIC CONSTANTS EAST CHANNEL

EAST CHANNEL

HARMONIC CONSTITUENT	PERIOD (HOURS)	FREQ. (CYCLES/MIN)$_{x10^{-3}}$	DEPTH 25 METERS				DEPTH 66 METERS				DEPTH 108 METERS			
			N. COMPONENT		E. COMPONENT		N. COMPONENT		E. COMPONENT		N COMPONENT		E COMPONENT	
			AMP(CM/S)	PHASE(°)	AMP(CM/S)	PHASE(°)	AMP(CM/S)	PHASE(°)	AMP(CM/S)	PHASE(°)	AMP(CM/S)	PHASE(°)	AMP(CM/S)	PHASE(°)
J1	23.10	0.7215	0.6	297.1	1.2	299.8	0.8	300.1	0.8	306.5	0.8	331.9	0.6	292.2
K1	23.93	0.6965	13.2	278.8	13.9	282.9	9.0	290.5	14.2	290.7	11.0	307.6	7.8	287.4
K2	11.97	1.3923	3.4	007.2	2.5	012.0	1.8	019.7	2.8	011.9	2.0	363.3	3.0	008.8
L2	12.19	1.3672	0.7	347.1	0.6	355.8	0.4	005.2	0.6	358.9	0.4	355.4	0.4	352.5
M1	24.83	0.6712	0.5	260.4	1.1	266.0	0.7	280.9	0.7	274.8	0.8	283.4	0.5	282.6
M2	12.42	1.3419	25.5	324.7	22.7	337.8	14.4	349.2	19.6	344.7	16.1	347.0	16.2	334.5
M4	6.21	3.6838	1.8	284.5	2.0	035.4	1.8	355.7	0.9	232.8	2.6	060.8	0.8	169.8
M6	4.14	4.0257	1.0	045.0	0.4	031.3	1.0	356.4	0.4	233.7	1.2	151.9	0.9	217.8
M8	3.10	5.3763	1.0	013.1	0.3	158.6	1.0	233.7	0.4	320.8	0.3	280.6	1.0	143.8
N2	12.66	1.3164	4.9	302.3	4.4	319.9	2.8	333.2	3.8	330.5	3.1	338.5	3.2	316.4
2N	12.90	1.2920	0.7	280.0	0.6	301.9	0.4	317.2	0.5	316.2	0.4	330.1	0.4	298.4
O1	25.82	0.6455	7.6	241.9	15.1	249.0	10.4	271.2	10.4	258.9	10.6	259.0	7.7	277.7
OO	22.31	0.7470	0.3	315.5	0.6	316.7	0.4	309.7	0.4	322.4	0.4	356.1	0.3	297.0
P1	24.06	0.6927	4.4	278.0	4.6	282.1	3.0	289.7	4.7	289.9	3.6	306.8	2.6	286.6
Q1	26.87	0.6203	1.5	223.5	2.9	232.1	2.0	261.6	2.0	243.1	2.0	234.8	1.5	272.9
2Q	28.01	0.5950	0.2	205.1	0.4	215.2	0.3	252.0	0.3	227.2	0.3	210.5	0.2	268.1
R2	11.98	1.3912	0.1	006.9	0.1	011.7	0.1	019.4	0.1	011.6	0.1	003.0	0.1	008.5
S2	12.00	1.3889	12.6	006.5	9.2	011.3	6.6	019.0	10.3	011.2	7.3	002.6	11.2	008.1
S4	6.00	2.7778	1.6	356.8	1.2	085.3	0.4	009.3	2.1	285.0	0.9	139.8	0.9	201.6
S6	4.00	4.1667	0.9	355.9	0.4	172.8	0.6	242.1	0.3	269.8	0.2	051.2	0.7	116.6
T2	12.02	1.3866	0.7	006.1	0.5	010.9	0.4	018.6	0.6	010.8	0.4	002.2	0.7	007.7
LAMBDA	12.22	1.3639	0.2	344.1	0.2	353.3	0.1	003.0	0.1	356.9	0.1	354.2	0.1	350.0
Nu2	12.63	1.4331	1.0	300.4	0.8	317.3	0.5	330.4	0.7	327.4	0.6	334.7	0.6	313.9
RHO1	26.72	0.6238	0.3	226.0	0.6	234.4	0.4	262.8	0.4	245.2	0.4	238.1	0.3	273.5

NOTE
PHASE ANGLE IS K' (MODIFIED LOCAL EPOCH K). K' IS THE PHASE ANGLE FOR THE 135°E (-9) TIME MERIDIAN.

(Burns, 1975)

TABLE 4-2(B). HARMONIC CONSTANTS WEST CHANNEL

WEST CHANNEL

HARMONIC CONSTITUENT	PERIOD (HOURS)	FREQ. (CYCLES/MIN)x10^{-3}	DEPTH 25 METERS				DEPTH 80 METERS				DEPTH 195 METERS			
			N. COMPONENT		E. COMPONENT		N. COMPONENT		E. COMPONENT		N COMPONENT		E COMPONENT	
			AMP(CM/S)	PHASE(°)	AMP(CM/S)	PHASE(°)	AMP(CM/S)	PHASE(°)	AMP(CM/S)	PHASE(°)	AMP(CM/S)	PHASE(°)	AMP(CM/S)	PHASE(°)
J1	23.10	0.7215	1.0	312.3	0.8	302.3	0.7	297.4	0.8	291.5	1.1	318.3	0.4	282.8
K1	23.93	0.6965	14.4	294.6	11.1	289.1	10.2	282.0	13.5	276.2	13.8	296.9	4.0	265.0
K2	11.97	1.3923	3.0	034.6	2.8	059.1	3.4	032.4	3.1	048.3	2.8	031.2	2.2	353.0
L2	12.19	1.3672	0.8	021.9	0.7	039.7	0.7	016.2	0.6	027.9	0.6	016.2	0.4	353.3
M1	24.83	0.6712	0.9	276.9	0.8	275.9	0.6	266.7	0.7	261.0	1.0	275.6	0.4	247.2
M2	12.42	1.3419	28.5	007.9	26.3	017.9	24.7	358.3	22.3	005.0	21.9	359.8	14.9	315.8
M4	6.21	3.6838	1.0	228.0	2.5	013.6	1.1	352.6	0.9	278.9	1.3	025.7	1.9	145.5
M6	4.14	4.0257	1.3	178.6	0.3	290.5	0.1	318.6	0.7	013.6	0.6	101.0	0.2	046.4
M8	3.10	5.3763	0.4	355.9	1.0	264.9	0.2	192.8	0.4	270.1	0.2	320.6	0.3	188.7
N2	12.66	1.3164	5.5	354.0	5.1	356.3	4.8	340.5	4.3	342.2	4.2	343.3	2.9	296.2
2N	12.90	1.2920	0.7	340.1	0.7	334.7	0.6	322.6	0.6	319.4	0.6	326.8	0.4	276.6
O1	25.82	0.6455	12.7	259.1	10.6	262.6	8.5	251.3	10.1	245.6	13.7	254.1	5.4	229.3
OO	22.31	0.7470	0.5	329.9	0.5	315.6	0.4	312.8	0.4	306.8	0.6	339.6	0.2	300.6
P1	24.06	0.6927	4.8	293.8	3.7	288.3	3.4	281.3	4.5	275.4	4.6	296.1	1.3	264.2
Q1	26.87	0.6302	2.5	241.5	2.1	249.3	1.6	236.0	2.0	230.3	2.6	232.7	1.1	211.5
2Q	28.01	0.5950	0.3	223.8	0.3	236.1	0.2	220.6	0.3	215.1	0.4	211.4	0.1	193.7
R2	11.98	1.3912	0.1	034.3	0.1	058.8	0.1	032.1	0.1	048.0	0.1	030.9	0.1	352.6
S2	12.00	1.3889	11.1	033.9	10.3	058.4	12.4	031.7	11.4	046.6	10.3	030.5	8.4	352.2
S4	6.00	2.7778	1.7	339.5	1.2	160.1	0.7	152.0	0.2	124.0	0.2	319.1	0.5	127.5
S6	4.00	4.1667	0.5	190.2	0.4	223.8	0.5	254.7	0.7	065.6	0.1	297.8	0.3	254.0
T2	12.02	1.3866	0.6	033.5	0.6	058.0	0.7	031.3	0.7	047.2	0.6	030.1	0.5	351.8
LAMBDA	12.22	1.3639	0.2	020.0	0.2	036.7	0.2	013.8	0.2	024.8	0.2	014.0	0.1	332.7
Nu2	12.63	1.4331	1.1	350.9	1.0	354.3	0.9	337.9	0.8	340.3	0.8	340.5	0.6	293.8
RHo1	26.72	0.6238	0.5	243.7	0.4	251.1	0.3	238.0	0.4	232.4	0.5	235.6	0.2	213.9

NOTE
PHASE ANGLE IS K' (MODIFIED LOCAL EPOCH K). K' IS THE PHASE ANGLE FOR THE 135°E (-9) TIME MERIDIAN.

(Burns, 1975)

which resulted from the NAVOCEANO Project Nugget Ranch during October-November, 1972. Table 4-2 shows the results of analysis by Burns (1975). The dominent constituents were M2 tide at all depths and in both channels, followed variously by K1, S2 and O1 tides, not necessarily in that order.

The Japan Hydrographic Office conducted current measurements during a 55-day period from August to October, 1969, as part of the comprehensive study of the Sea of Japan (Science and Techn. Agency, 1971). Figure 4-14 shows the distribution of flood and ebb currents and non-tidal currents from the JHO observations in 1972.

Lee (1970) in 1968 and 1969 performed current measurements on 4 levels at 3 locations in the West Channel. The greatest observed current speed in his records was 3.3 knot occurring in both NE and SW directions. The August 1968 records revealed the occurrence of an outflow from the Sea of Japan at levels lower than 50 m. Net volume transport in the West Channel remained stable around 1.2 Sv during the three separate measurements in August and December, 1968 and March, 1969.

The water mass characteristics in the Tsushima Strait have been investigated by a number of investigators. Figure 4-15 shows time histories of water temperature at various locations adjacent to the Tsushima Strait (Seikai Regional Fisheries Research Laboratory, 1973). An alternating sequence of a seasonal summer thermocline to about 50 - 100 m below the surface and a good mixing in the water column during winter months is a characteristic feature throughout the whole adjacent region including the East and West Channels. It is also interesting to notice that the appearance of a cold bottom water, pronounced only in the East Channel, exhibits an emulatory relationship with the thermocline: when the cold bottom water is well developed, the thermocline is shallower, and when it is less developed, the thermocline is deeper. This may imply that the degree of encroachment of the Japan Sea Cold Water may have bearings on the effective cross-sectional area of East Channel through which the water arriving from the south can be accomodated. Also interesting is the fact that the behavior of isotherms in the East Channel resembles that off the Goto Islands, while the behavior of isotherms in the West Channel is more similar to that of the Jeju Strait.

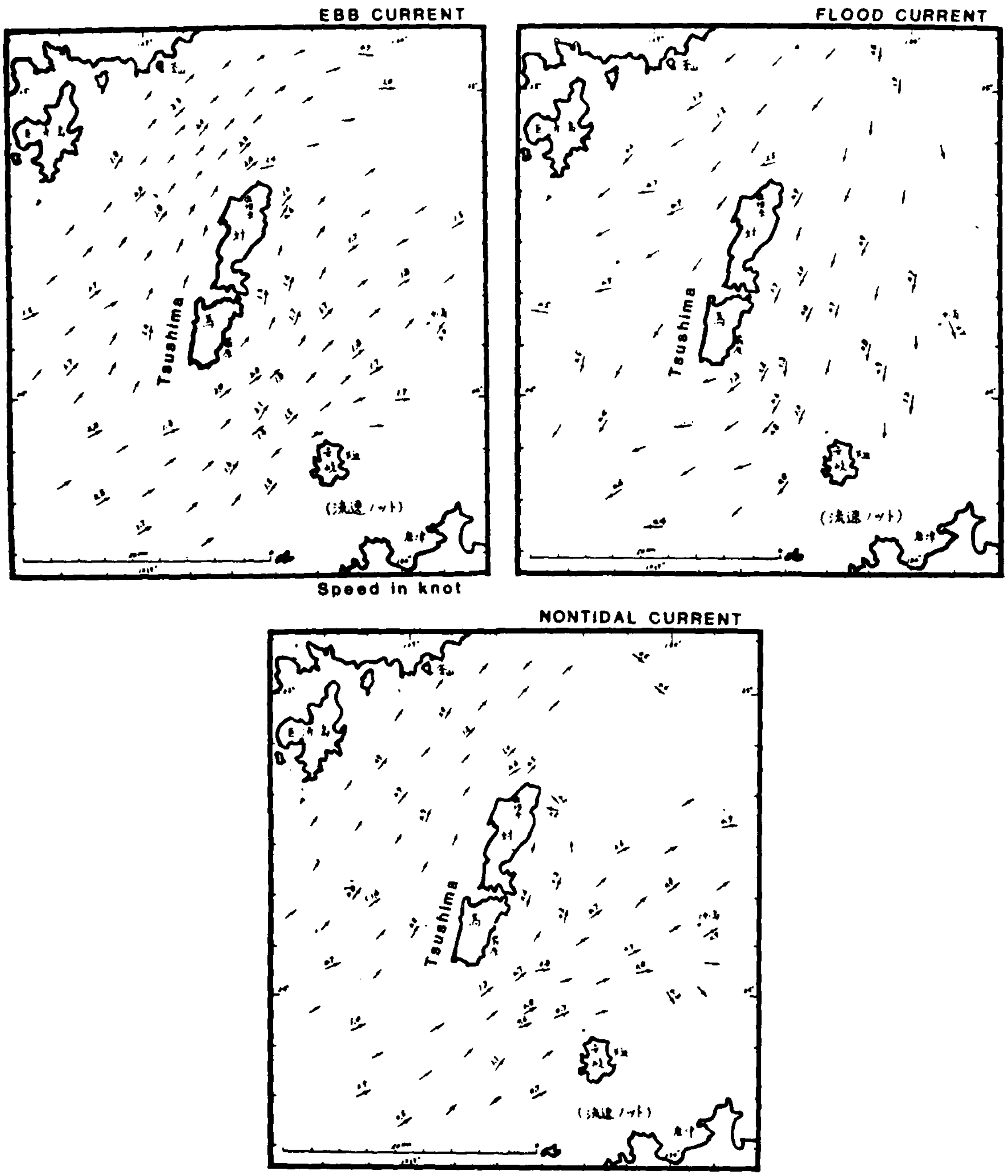
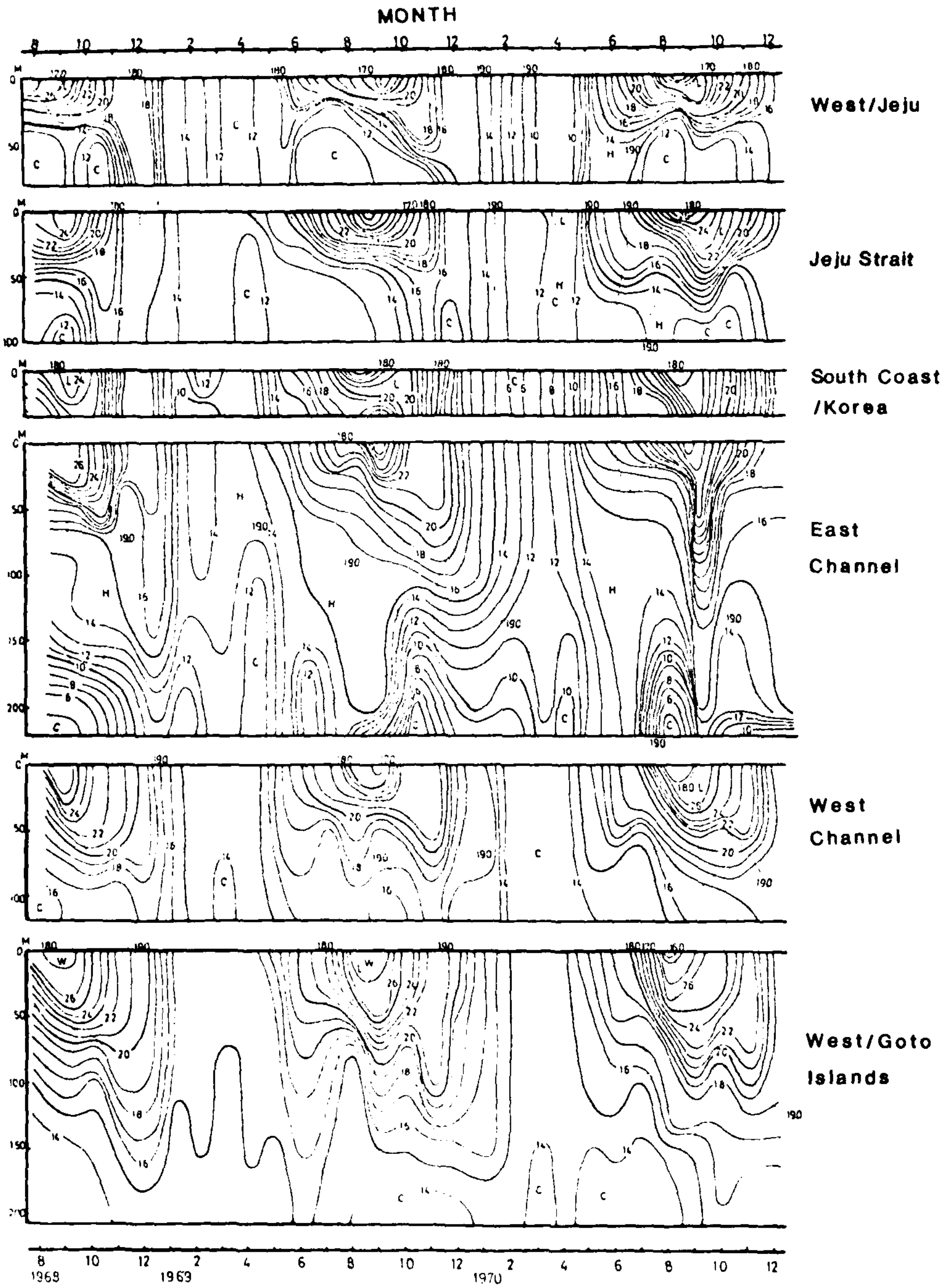


Figure 4-14. Tidal and non-tidal currents through Tsushima Strait from JHO surveys in 1969.



(Courtesy of Seikai R.F.L.)

Figure 4-15. Time history of temperature profile at selected positions adjacent to Tsushima Strait.

The Korean Ocean Research and Development Institute in 1978 compiled a comprehensive analysis of temperature data in the Korean waters (Hahn, 1978). This report provides plottings of temperature data on the basis of the sectional surveys which mainly took place between 1961 and 1975, and some dating back to 1922. It gives a particularly detailed presentation of data along Lines 207 and 208 which traverse the Tsushima Strait West Channel and a downstream area, respectively.

Figure 4-16 shows mean monthly temperature distribution at two levels (surface and -100 m) on a bimonthly basis, extracted from the KORDI report. Figure 4-17 shows mean monthly temperature for all sectional survey stations of Lines 207 and 208. Figure 4-18 shows mean temperature sections on a bi-monthly basis along Lines 207 and 208. These two Lines, which both run astride the Tsushima Strait, have been most intensively surveyed by the Korean agencies, data for Line 207 dating back to 1922 and that for Line 208 to 1932.

Dynamics close to the coastal boundary in the Tsushima Strait region has been a subject of major interest to fisheries oceanographers both in Japan and Korea. The coastal waters from the South Korean coast and from the western and northern coast of Kyushu, converge on both flanks of the Tsushima Warm Current. Additionally, the North Korea Cold Current moves southward along the east coast of Korea, bound for the West Channel.

Tsujita (1952a, b, c) documented extensively the occurrence of frontal structures, meso-scale eddies and circulations in the region of the Tsushima Strait (see also Chapter 4: Annotated Bibliography: Tsushima Strait). Ogawa et al. (1977) pointed out that the distinct low-salinity waters off the western and northern coast of Kyushu were predominantly influenced by the low-salinity water originating from the upper water of the Tsushima current offshore, rather than the influx of fresh water from local rivers. As already mentioned, Gong (1971) showed distributions of the South Korean coastal front exhibiting seasonal expansion and contraction in the West Channel of the strait (see Chapter 4: Annotated Bibliography, Tsushima Current). Recently, Huh (1973, 1976) applied a satellite surveillance method to monitor the spatial behavior and fine details of the South Korean coastal fronts with considerable success.

There have also been intensive studies by Korean oceanographers on the upwelling processes occurring along the coast facing the West Channel. Figure 4-19, adapted from Lim and Chang (1969), shows

FEBRUARY

(Courtesy of KORDI)

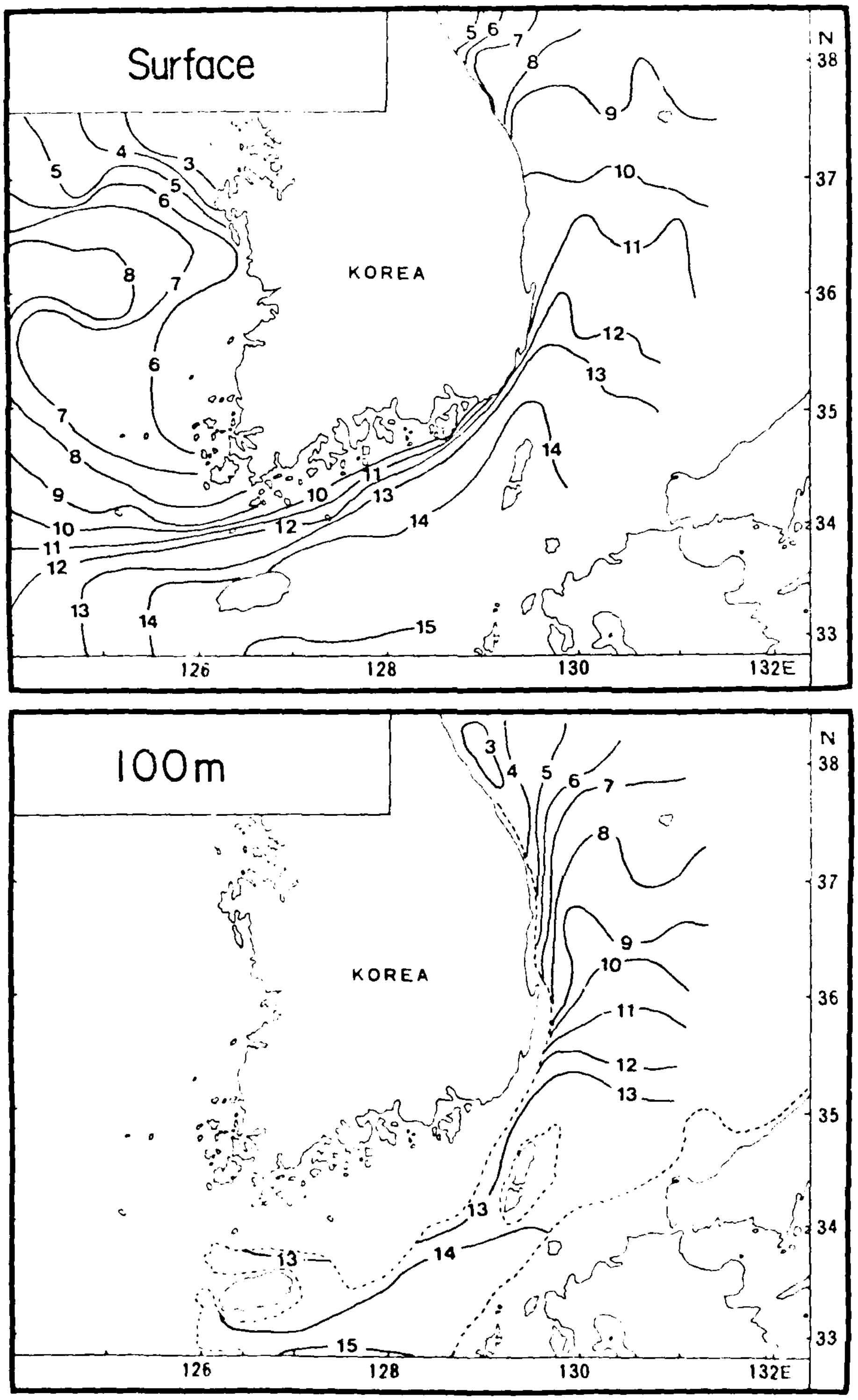
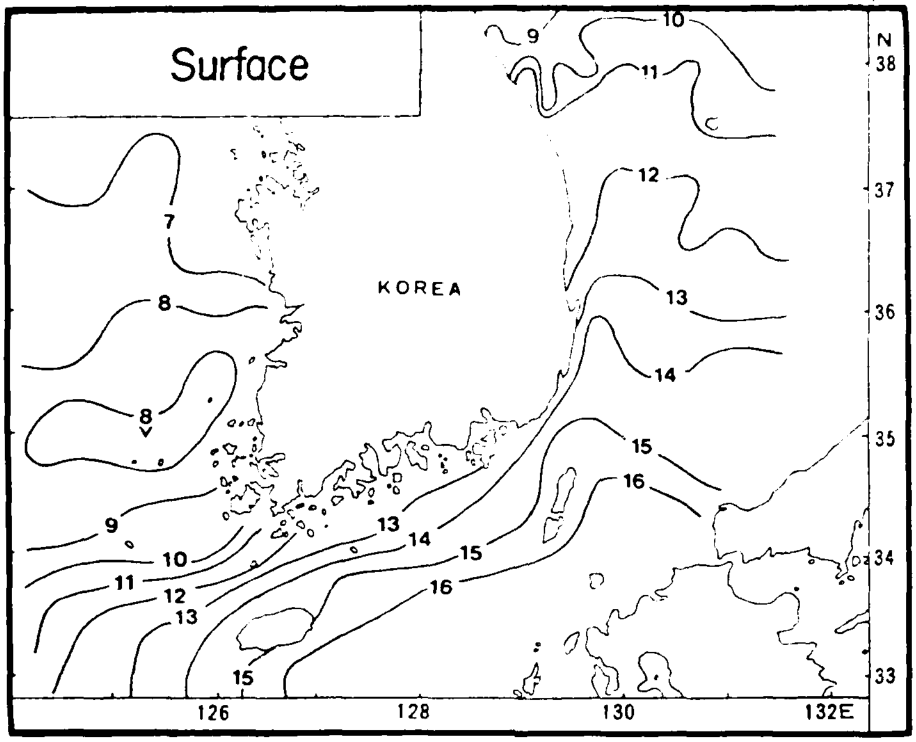


Figure 4 16(A). Mean monthly temperature distribution at the the surface and -100 m around Korea (1961-75).

APRIL (Courtesy of KORDI)



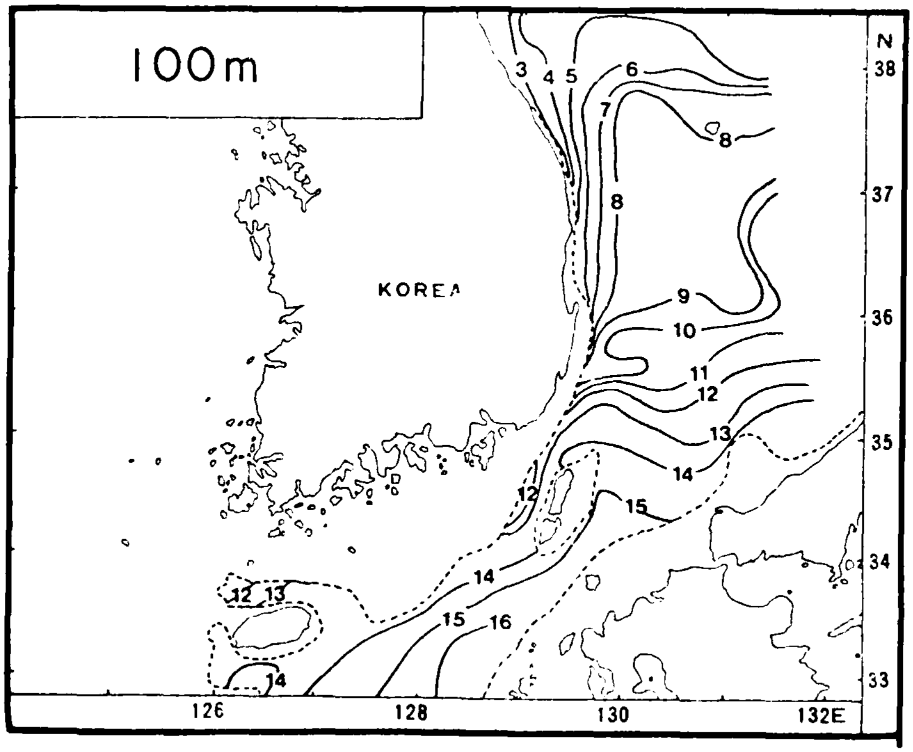


Figure 4-16(B). Mean monthly temperature distribution at the the surface and -100 m around Korea (1961-75).

JUNE (Courtesy of KORDI)

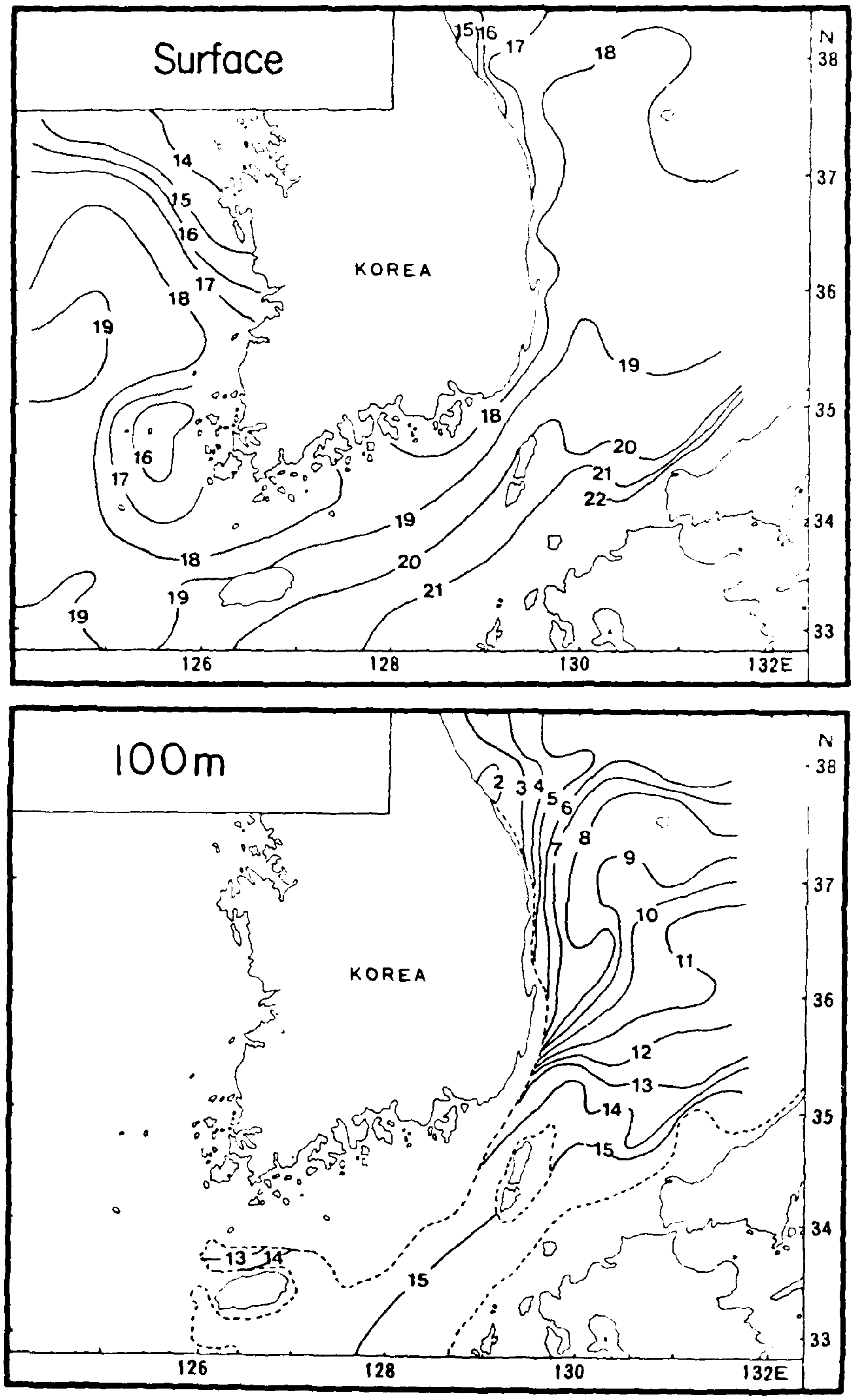


Figure 4-16(C). Mean monthly temperature distribution at the the surface and -100 m around Korea (1961-75).

AUGUST (Courtesy of KORDI)

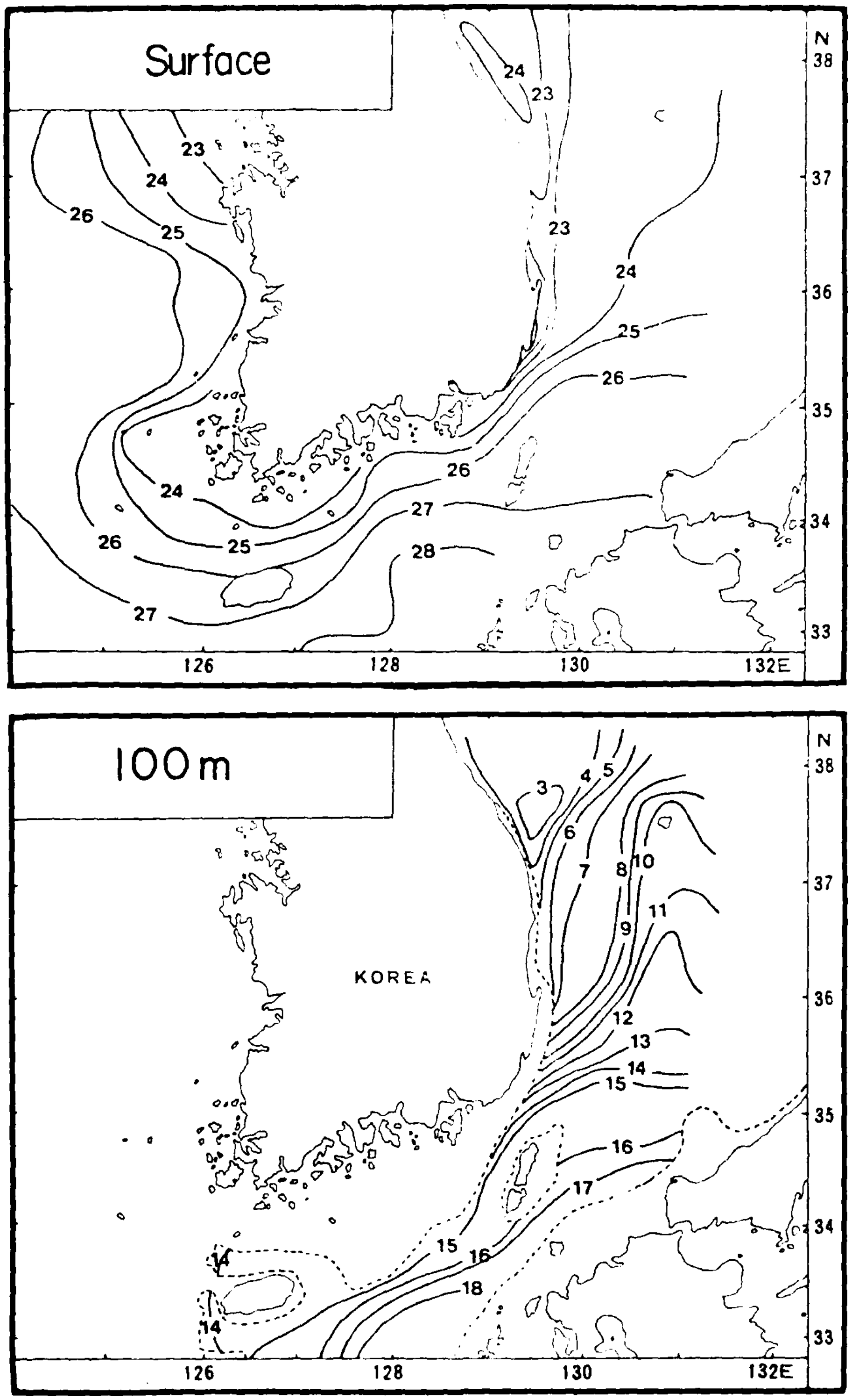


Figure 4.16(D). Mean monthly temperature distribution at the the surface and -100 m around Korea (1961-75).

OCTOBER (Courtesy of KORDI)

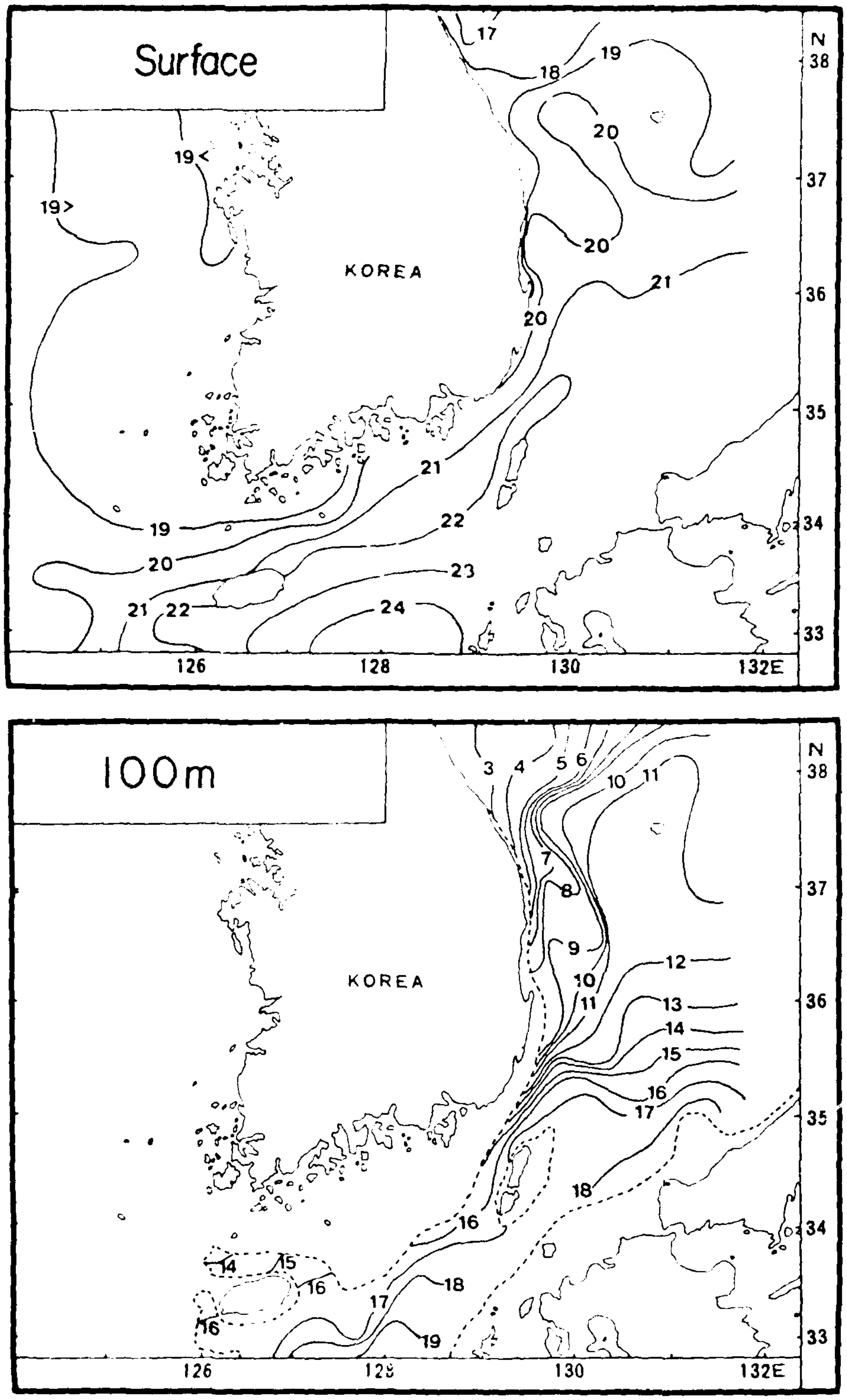


Figure 4-16(E). Mean monthly temperature distribution at the the surface and -100 m around Korea (1961-75).

DECEMBER (Courtesy of KORDI)

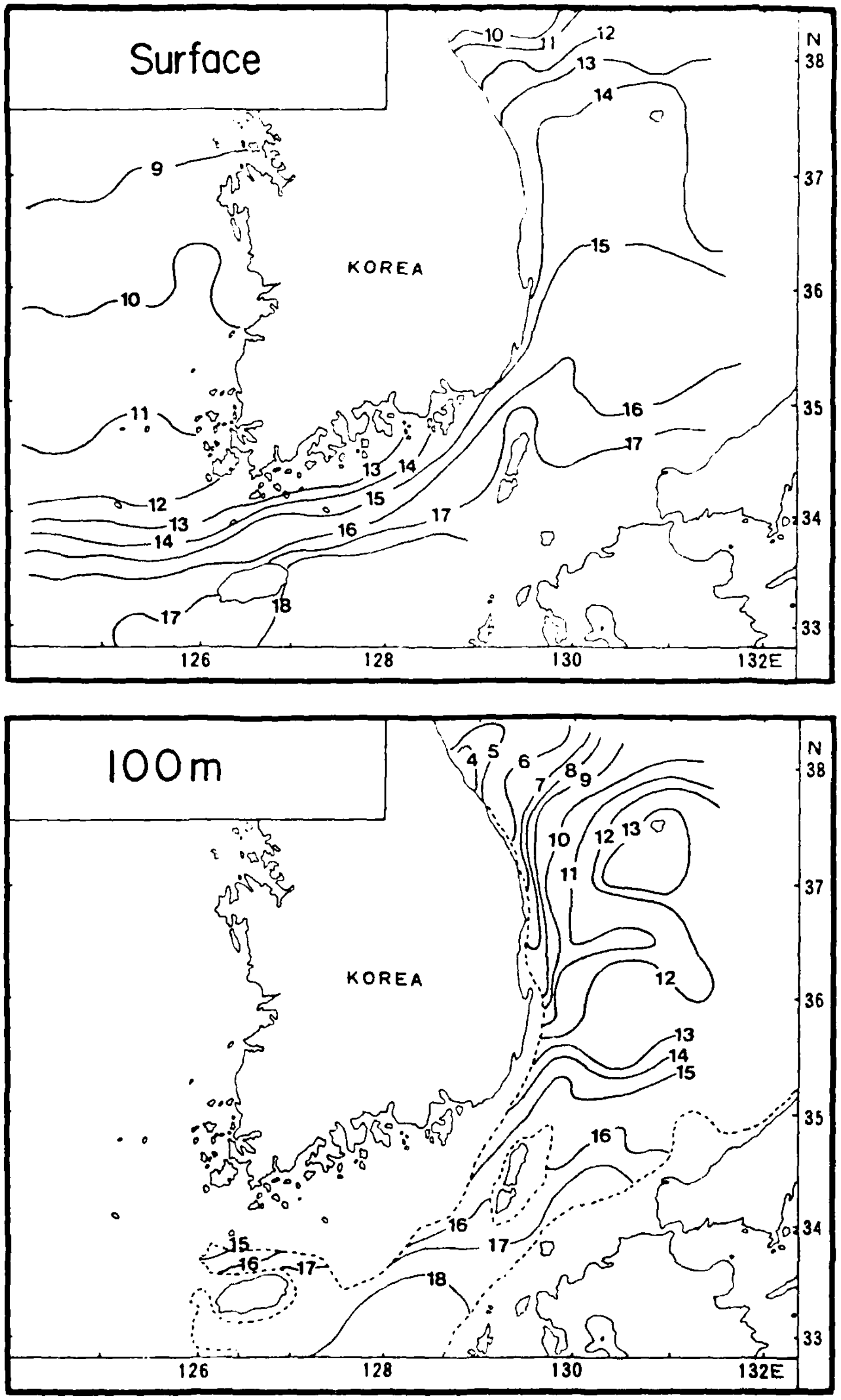
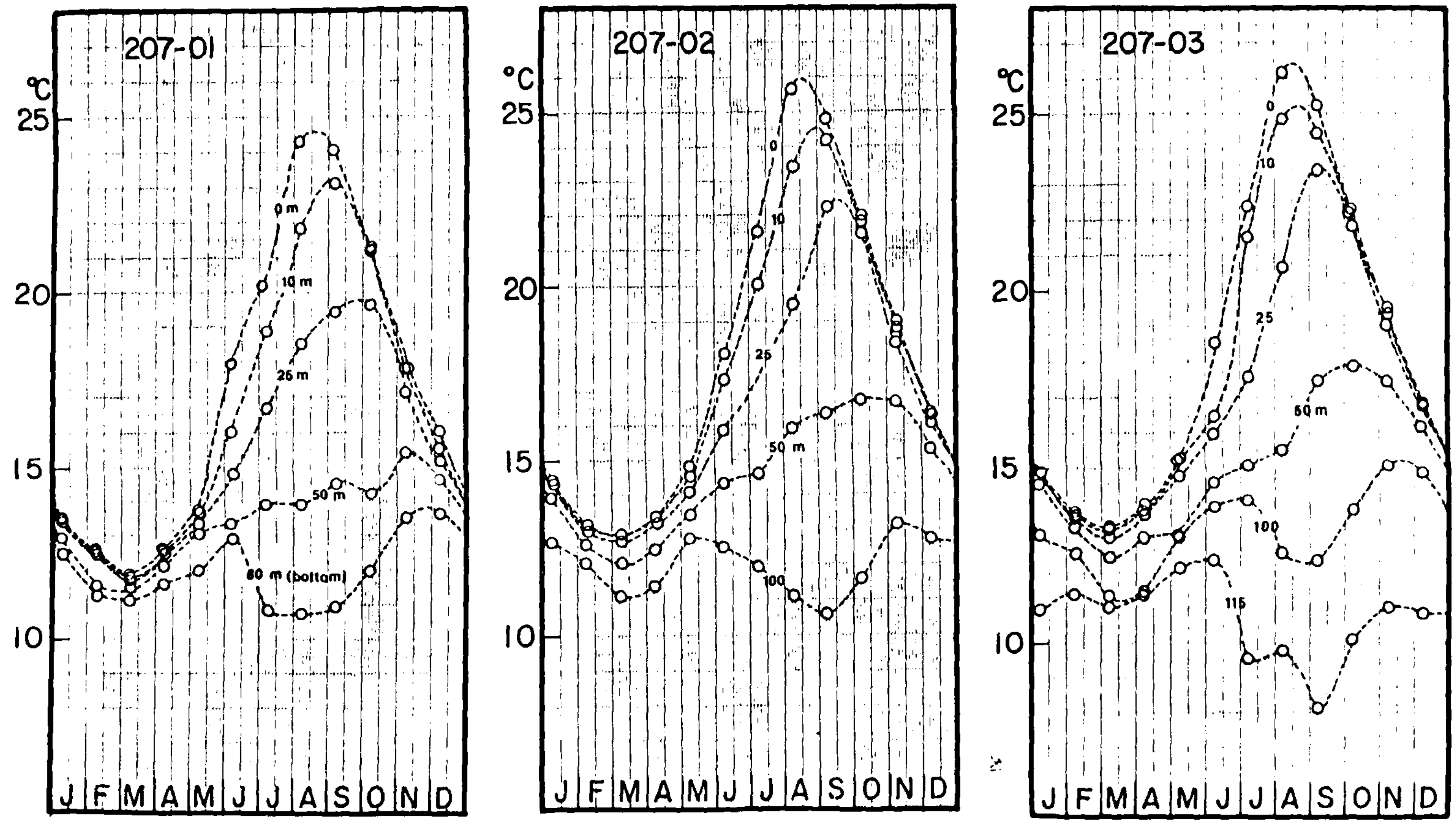
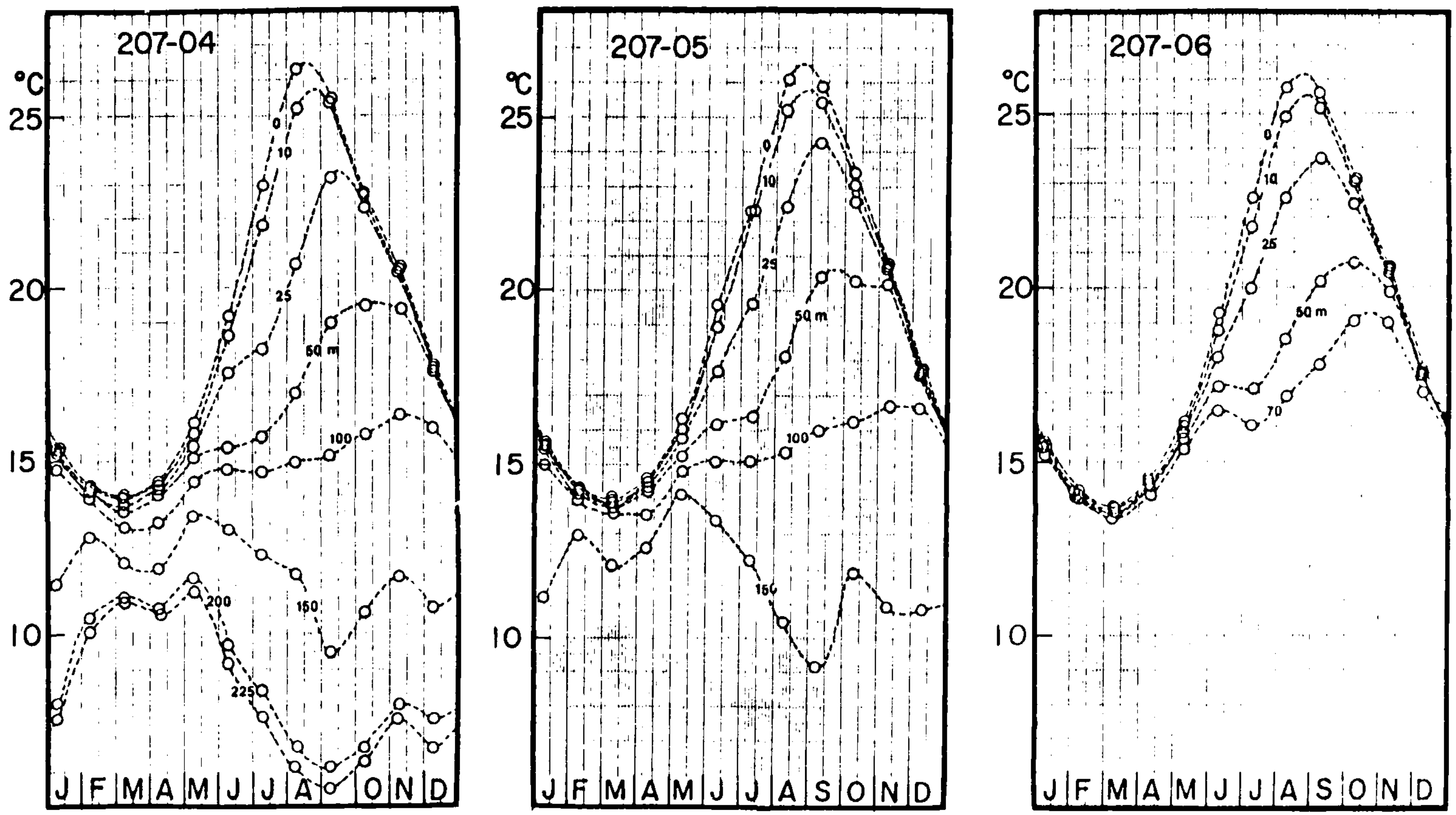


Figure 4.16(F). Mean monthly temperature distribution at the the surface and -100 m around Korea (1961-75).



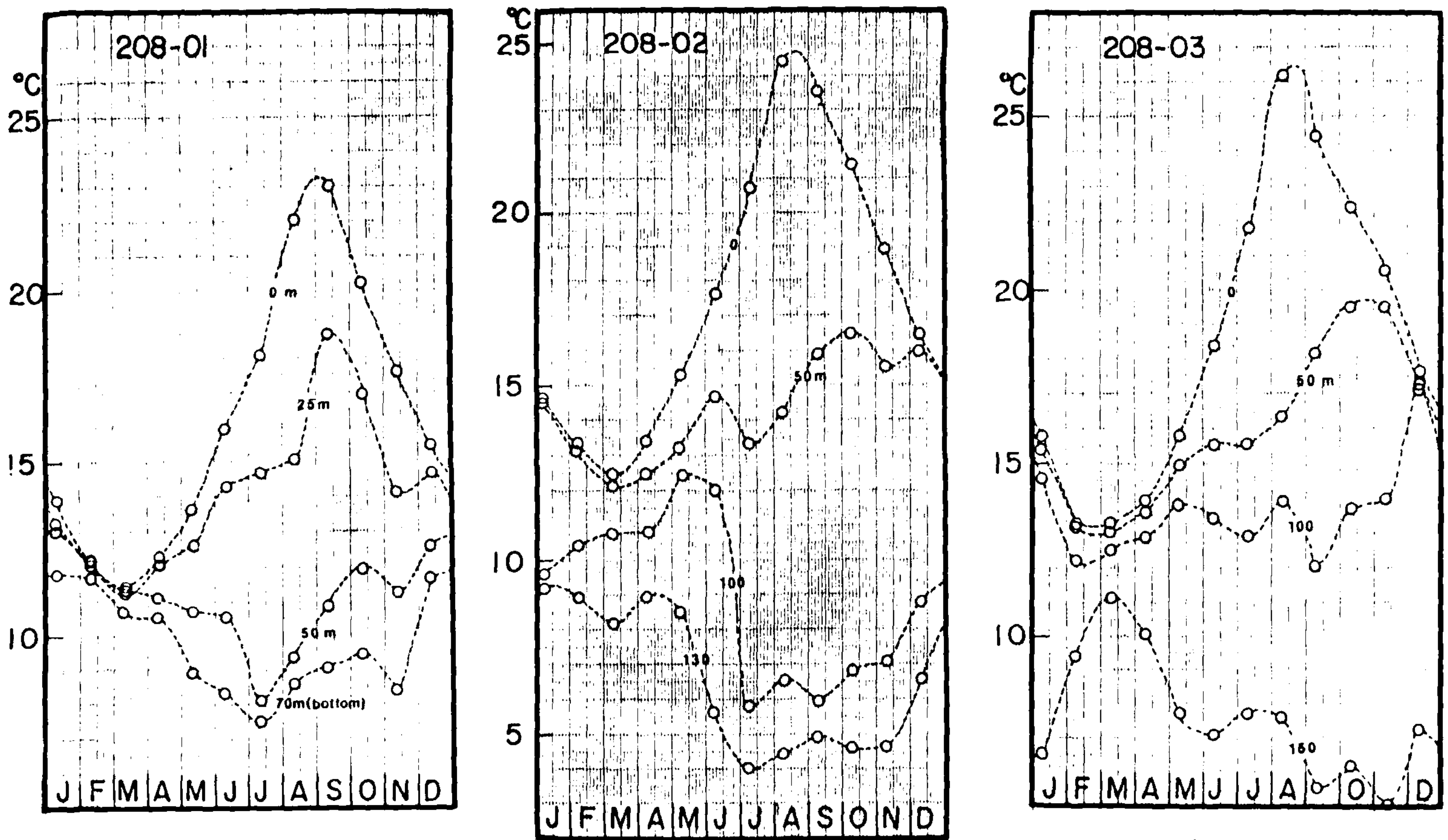
(Courtesy of KORDI)

Figure 4-17(A). Mean monthly temperature at sectional serial stations in the vicinity of Tsushima Strait: Lines 207 and 208. (Data: 1922-43 for Line 207, 1932-44 for Line 208)



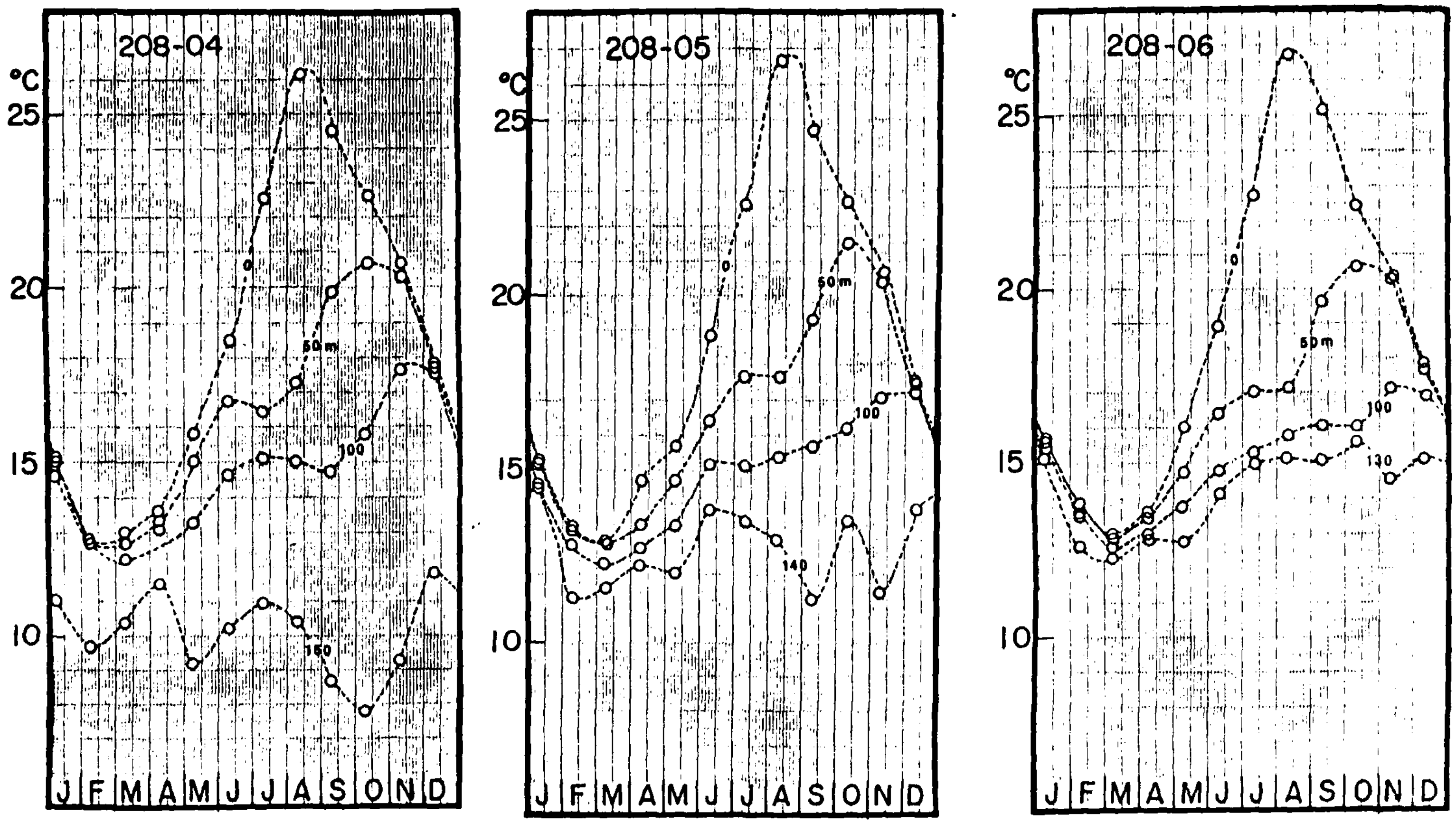
(Courtesy of KORDI)

Figure 4-17(B). Mean monthly temperature at sectional serial stations in the vicinity of Tsushima Strait: Lines 207 and 208. (Data: 1922-43 for Line 207, 1932-44 for Line 208)



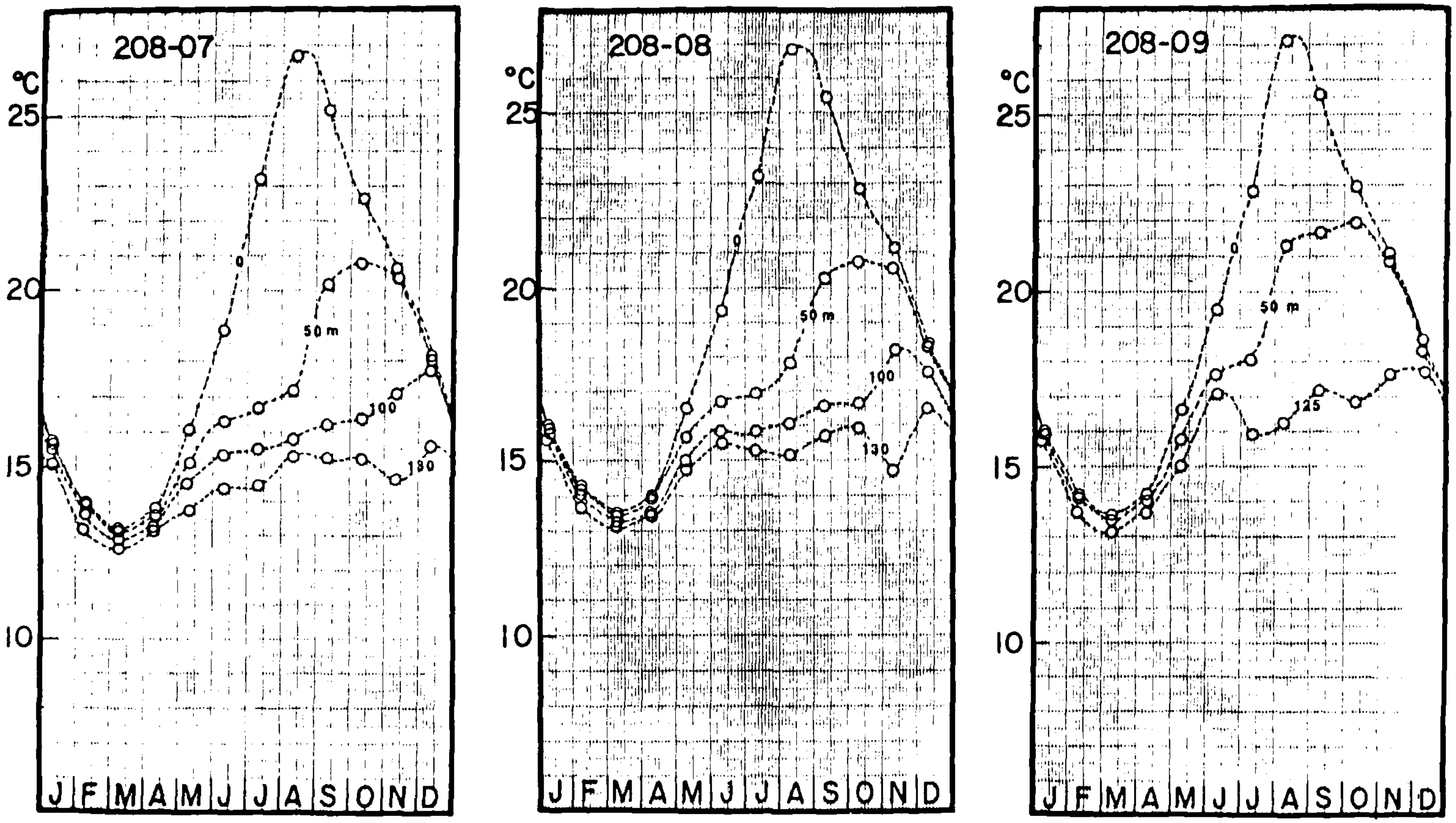
(Courtesy of KORDI)

Figure 4-17(C). Mean monthly temperature at sectional serial stations in the vicinity of Tsushima Strait: Lines 207 and 208. (Data: 1922-43 for Line 207, 1932-44 for Line 208)



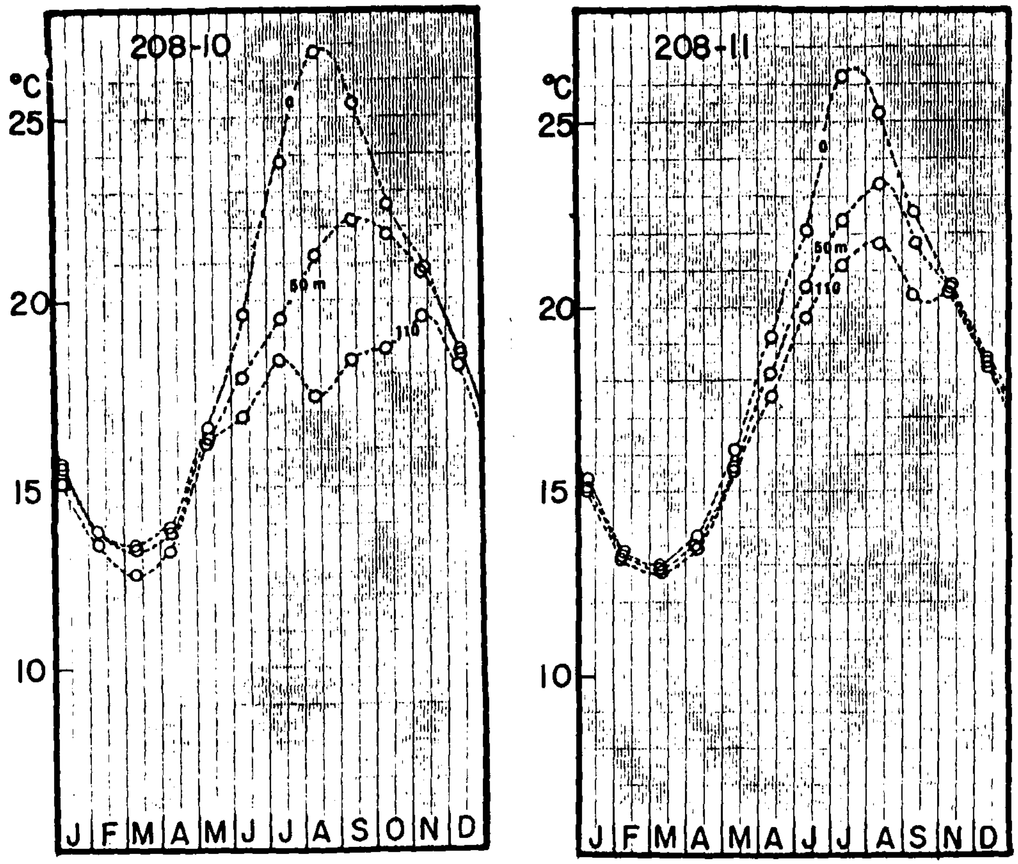
(Courtesy of KORDI)

Figure 4-17(D). Mean monthly temperature at sectional serial stations in the vicinity of Tsushima Strait: Lines 207 and 208. (Data: 1922-43 for Line 207, 1932-44 for Line 208)



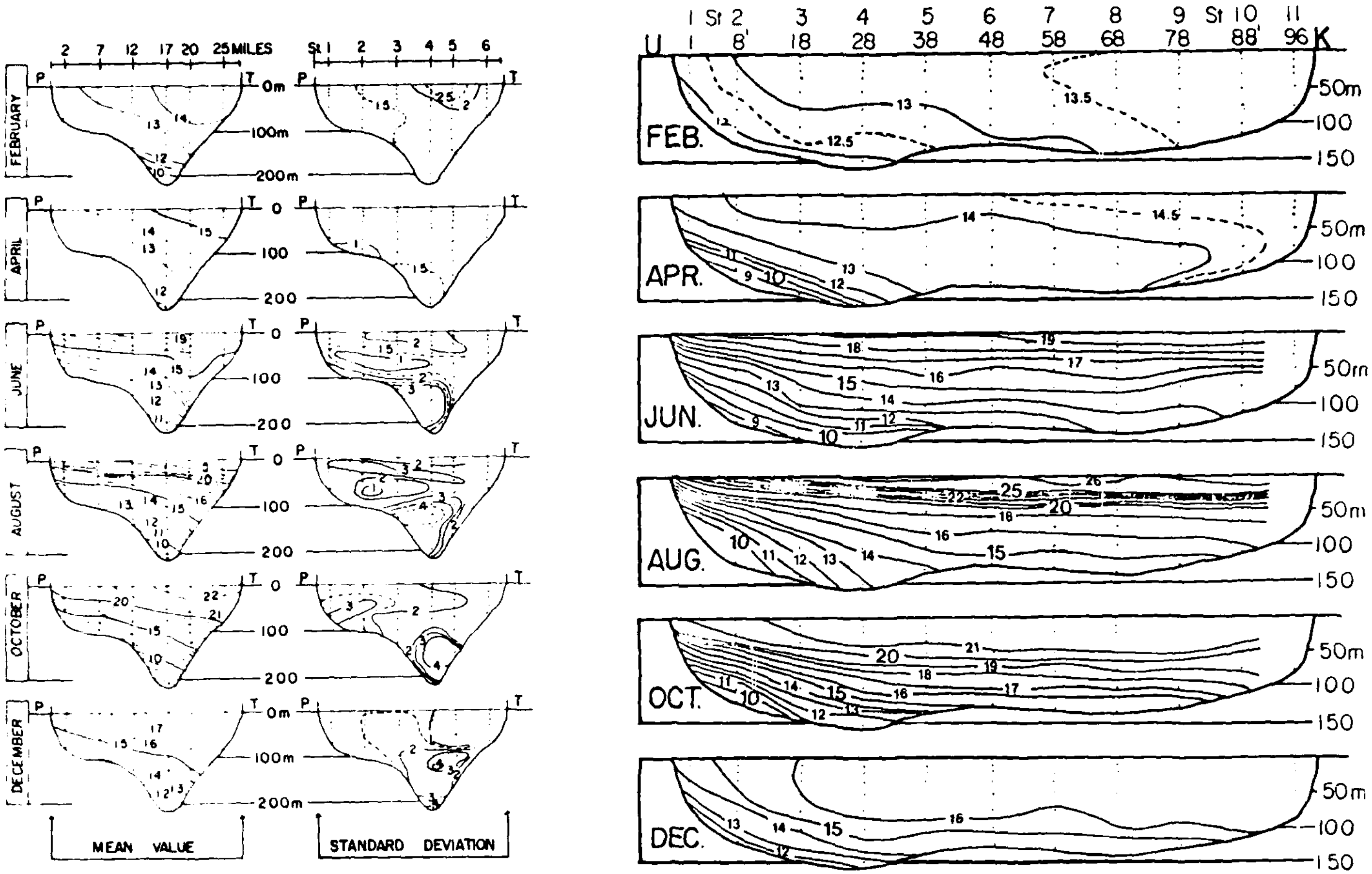
(Courtesy of KORDI)

Figure 4-17(E). Mean monthly temperature at sectional serial stations in the vicinity of Tsushima Strait: Lines 207 and 208. (Data: 1922-43 for Line 207, 1932-44 for Line 208)



(Courtesy of KORDI)

Figure 4-17(F). Mean monthly temperature at sectional serial stations in the vicinity of Tsushima Strait: Lines 207 and 208. (Data: 1922-43 for Line 207, 1932-44 for Line 208)



LINE 207

LINE 208

NOTE: P = Pusan (or Busan) T - Tsushima, U = Ulgi, K = Kawajiri-Misaki

Figure 4-18. Mean temperature sections across Tsushima Strait (Courtesy of KORDI).

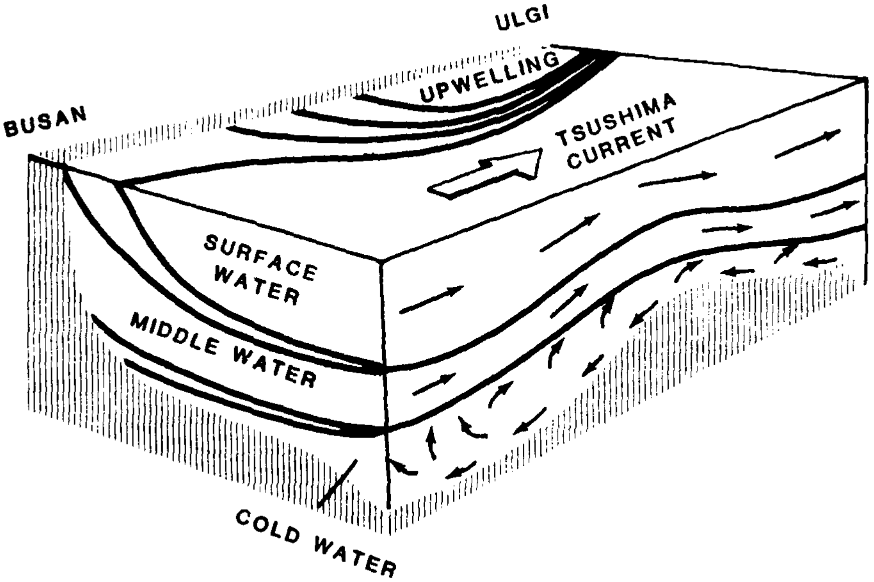


Figure 4-19. Schematic showing of water mass distribution in the vicinity of upwelling zone on the east coast of Korea. (Adapted from Lim and Chang, 1969.)

this process. Figure 4-20 shows the temperature sections during the upwelling season along Lines 207 and 208, both running across the Tsushima Strait. The water contained in the upwelling region is characterized by temperatures 3 - 10^{o}C and salinities 34.0 - 34.4 PPT. Once on the surface, the cold water spreads in the alongshore direction adjacent to the coast, its southerly edge approaching as far as the Busan-Tsushima line (Line 207).

Lee (1978) postulates that the upwelling process observed during summer off Ulsan results from the surface divergence associated with an anticlockwise gyre which is driven by the inflow of the Tsushima Warm Current through the West Channel.

4.2 Tsugaru Strait

<u>Overview of Problems</u>

Oceanographic processes relating to the Tsugaru Strait are discussed for three geographical regions: the inflow region, the channel, and the outflow extension.

In the inflow region, the proportion of the volume transport of the Tsushima Warm Current which flows into the Tsugaru Strait has been and still remains the subject of intense studies. The problem may be expressed in three distinct questions: (1) What is the dynamic structure of the approaching Tsugaru Warm Current? (2) How the stratification in the approaching current interacts with the shallow sill at the entrance? (3) What is the dynamic balance of the inflow at the entrance?

The dynamic structure of the approaching current has not been sufficiently elucidated to determine whether the current exists as separate branches or, as the prevailing view suggests, the branches have regrouped themselves into a single coherent stream in the vicinity of Nyudo-zaki. In the view of the present writer, the degree to which the branches would regroup should depend upon the location and strength of the Japan Sea Polar Front, whereas the literature fails to give sufficient emphasis on this apparent possibility. GEK data and drift bottle studies indicate that the branches more or less retain their identity while tending to converge near the Tsugaru Strait.

The limited depth of the sill at the entrance would allow only the water above or close to this depth to be drawn into the channel. This is a classical case of selective withdrawal — a process well known in estuary hydrodynamics. Although a growing number of

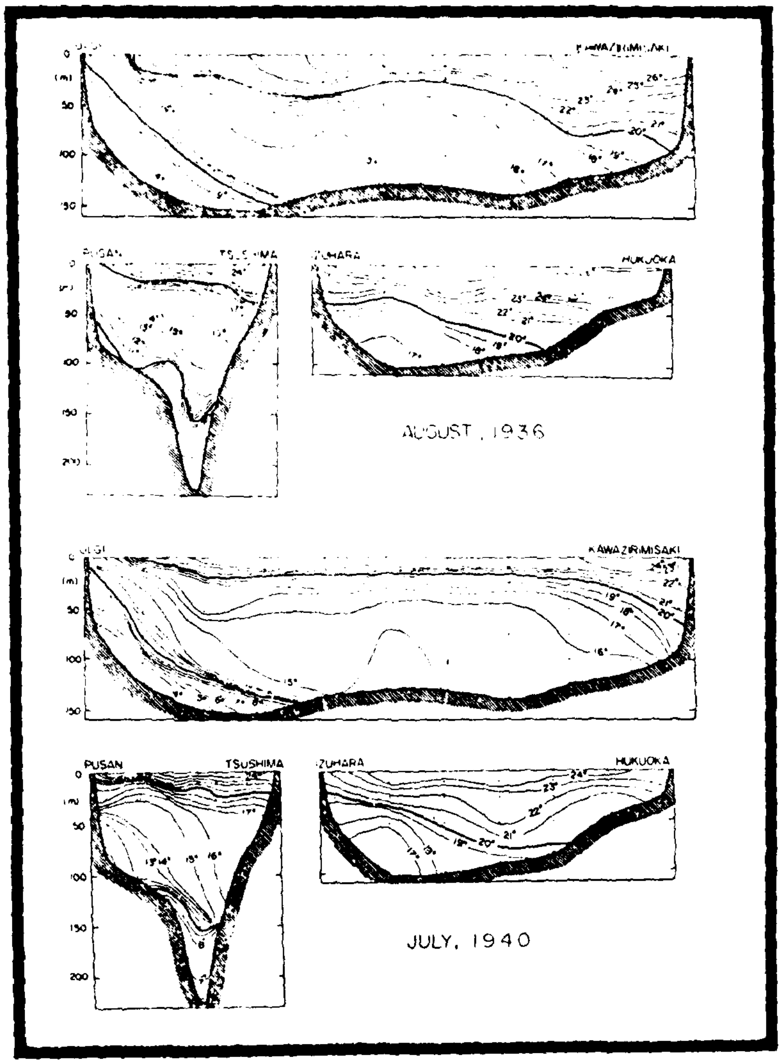


Figure 4-20. Temperature sections across Tsushima Strait during two upwelling events (Lim and Chang, 1969).

studies are addressing the subject of water mass stratification in the inflow region, relatively few studies have focused on the interaction between the stratification and the sill.

The attention of the dynamics of current in the strait channel was partly instigated by the need for tidal current prediction and partly by the navigational hazards posed by a large number of drifting mines found in the channel for several years after World War II. The subject received detailed hydrodynamic analysis in a recent study by Conlon (1981).

The oceanographic processes in the region of the Tsugaru Warm Current extension are highly complex as the region is characterized by the interaction among the Oyashio, the Kuroshio extension, the Oyashio Front, and the outflow from the Tsugaru Strait. An increasing use of satellite remote sensing imagery is being made recently by Japanese oceanographers to supplement cruise data in this region. Possible occurrence of distinct modal behaviors of the outflow as a function of the internal Rossby radius of deformation, recently suggested by Conlon (1981), is an interesting insight.

Inflow Region

Figure 4-21 shows the general geographical features of the Tsugaru Strait with a 200 m isobath. The coastlines surrounding the Strait are quite irregular. At the western entrance, it is only about 20 km wide between Tappi-zaki and Shirakami-misaki (i.e., -zaki and -misaki denoting "cape"). The channel further narrows to about 17 km at its eastern end between Shiokubi-misaki and Oma-zai. The length of the channel between these two narrow widths is about 70 km. The distance between the western most point (Tappi-zaki) and the eastern most point (Shiriya-zaki) along the course of the channel is about 120 km. The shallowest portion of the Strait is located at the western entrance between Tappi-zaki and Shirakami-misaki where the water depth rises to about 130 meters, forming a sill. Between here on to the east, for about 60 km, the channel depth is generally deeper than 200 meters, but the depth greater than 200 meters comes to a virtual nil at the eastern end of the channel between Oma-zuki and Shiokubi-misaki. It then again widens while becoming deeper further to the east as the channel opens to the Pacific Ocean.

The dynamics governing the separation of the Tsushima Warm Current into the Tsugaru Strait and the associated volume transport have been among the key concerns of Japanese oceanographers. The Japan Hydrographic Office (JHO) has been interested in these subjects as they impact predictability of currents through the Strait. The Japan Meteorological Agency's (JMA) interest stemmed mainly from the concern over the hydrography in the northern Tohoku region of the Pacific side where the outflow of the Tsugaru Warm Current and its subsequent expansion interact with

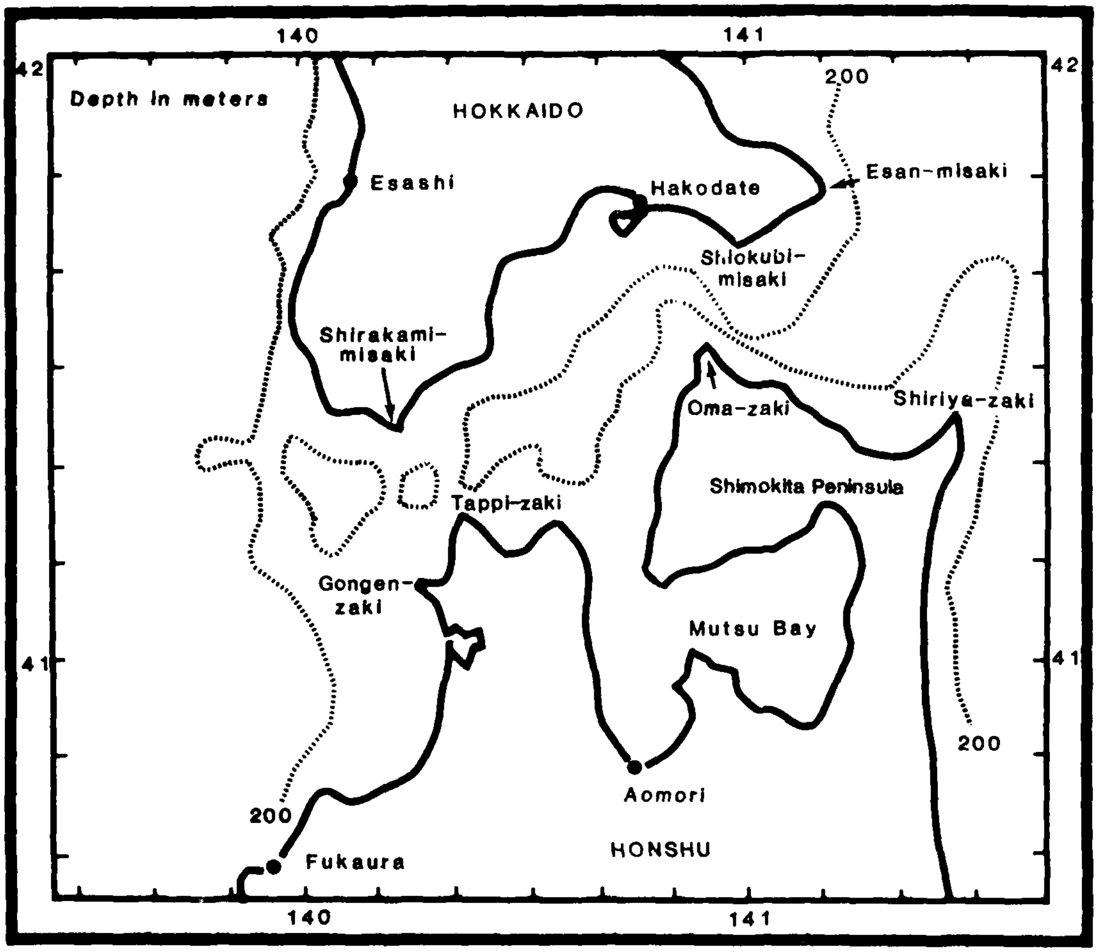


Figure 4-21. General geographical features of the Tsugaru Strait region.

the dynamics of the Oyashio and the Kuroshio. The Japan Fisheries Agency (JFA) and its affiliated prefectural fisheries stations were mainly concerned over the formation and distribution of water masses and their meso-scale dynamics both in the Tsugaru and Soya Straits regions as these are sensitively impacted upon by the volume transport and the inflow dynamics at the Tsugaru Strait. It goes without saying that the amount of volume separating into the Tsugaru Strait from the Tsushima Warm Current will be among the major governing factors affecting the volume transport into the Soya Strait.

Several important aspects of the problem concerning the inflow dynamics at the Tsugaru Strait may be summarized as follows:

(1) The Tsushima Warm Current, after entering the Sea of Japan and further undergoing complex maneuvers in the downstream region of the strait, consolicates itself into a more or less coherent boundary current against the northwestern coast of Honshu at a location approximately 130 km south of the Tsugaru Strait off Nyudo-zaki (latitude 40°N). It is not known exactly why and how this re-consolication takes place. However, it is the view of the present writer that the process is possibly related to the behavior and location of the Japan Sea Polar Front which exhibits seasonal fluctuation centered around this latitude. If this is the case, the pre-inflow characteristics of the Tsushima Warm Current are likely to undergo seasonal fluctuation influenced partly by the Japan Sea Polar Front and partly by the seasonal volume transport at the Tsushima Strait. Volume transport bound for the Tsugaru Strait off Nyudo-zaki was estimated to vary between about 2 and 4 Sv (Science & Technology Agency, 1979). It is known to increase from spring toward summer and fall, with an annual maximum occurring in August.

(2) Since the water masses of the Tsushima Warm Current in the inflow region have experienced a diversity of formation and alternation of the original Tsushima Warm Current between the Tsushima Strait and the point of reconsolidation south of the Tsugaru Strait, the inflow dynamics at the Tsugaru Strait is deemed inseparable from the processes of inflow extension and circulation downstream of the Tsushima Strait.

(3) Since the Tsugaru Strait has a sill at the inflow section only about 130 m deep, and also since the water in the approaching Tsushima Warm Current is stratified both vertically and horizontally, the inflow process is very likely a case of selective withdrawal - a situation in which only the water within certain ranges of depth in proximity to the Strait is drawn into the channel. This notion appears to be supported by water mass analyses in the inflow region ([illegible] 1?54; Science & Technology Agency, 1971) and also by the [illegible] drift bottle experiments (Akagawa, 1955; Science & [illegible]gency, 1971).

Figure 4-22 shows temperature and salinity distribution at a 50-m level in the region where the Tsushima Warm Current makes an approach toward the Tsugaru Strait, based on the recent data collected by the JFA during the 3-Agency Comprehensive Study of the Tsugaru Strait, 1975-1977. The boundary of the Tsushima Warm Current generally is located along the 6 - 7°C isotherm.

In March, the Tsushima Warm Current exhibits temperatures around 8°C, and salinities around 33.9 PPT, its offshore boundary near 7°C and 34.0 PPT indicating a width of nearly 40 km off Iwasaki (40°40'N). In May, temperatures and salinities both rose slightly to 8 - 10°C and 33.5 - 34.2 PPT, respectively, in the warm current region, with a concurrent increase of the width to about 50 km. In July, there has been a rapid rise in both temperatures and salinities to 8 - 14°C and 34.10 - 34.50 PPT, respectively. The width has now increased to more than 60 km off Iwasaki. There has also occurred a conspicuous bending of the isotherms, suggesting that the Tsushima Warm Current is now tending to veer east toward the Tsugaru Strait. In September, this tendency has further increased to such an extent that the Tsushima Warm Current is headed directly to the Tsugaru Strait. Temperatures and salinities in the warm current region are now 8 - 18°C and 34.10 - 34.50 PPT, respectively. The core of the warm current in September is located about 15 km west of Iwasaki and about 25 km off the coast at 41°N, bound for the Tsugaru Strait. The bending of the warm current toward the Tsugaru Strait has also induced shoreward encroachment of the cold offshore water, indicating that the Tsushima Warm Current in its entirety has turned toward the Tsugaru Strait.

Akagawa (1954) recognized the presence of several typical water masses in the inflow region of the Tsugaru Strait, each with distinct origin and processes of formation. Although the water mass classification in the Tsushima Warm Current has since been considerably more fine-tuned, the original grouping proposed by Akagawa essentially retains their validity today.

These water masses are:

1. Coastal water (C)
2. Tsushima Warm Current Surface Water (Ts)
   - 2-1. Coastal surface water (Tsc)
   - 2-2. Core surface water (Tsb)
   - 2-3. Cold-current mixed surface water (Tsl)

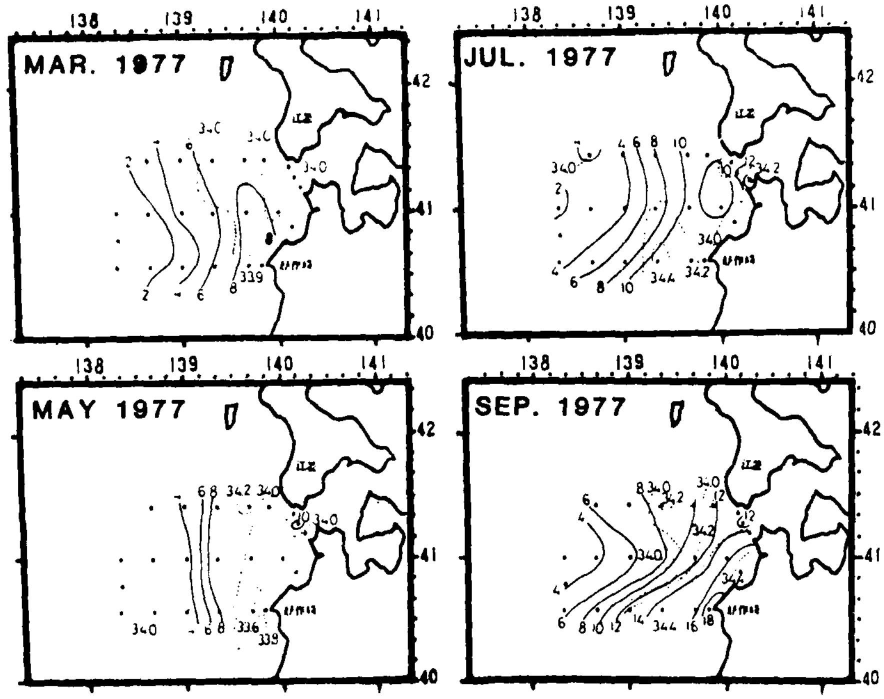


Figure 4-22. Seasonal temperature and salinity distribution in the approach region to Tsugaru Strait.

3. Tsushima Warm Current mid-water (Tm)
4. Liman Cold Current surface water (L)
5. Japan Sea mid-water (M)
6. Japan Sea deep water (D)
7. Japan Sea bottom water (B)

Coastal water (C): The coastal water, which is dominantly influenced by the land, has typical low salinity and high D.O. and nutrient salts. It occurs in the vicinity of the Tsugaru Strait, off Iwasaki, Mutsu Bay, between Esashi and Cape Shirakami, and near Hakodate.

Tsushima Warm Current surface water (Ts): This water generally occupies a shallow 25m of the warm current, and forms a front on its western boundary against the Liman Cold Current, located about 60 miles west of the entrance of the Tsugaru Strait in summer. This water mass consists of three subgroups with distinct origin and processes of formation: Coastal surface water (Tsc), core surface water (Tsb), and cold-current mixed surface water (Tsl).

Coastal Surface Water (Tsc): It originates in the East Channel of the Tsushima Strait and moves as a boundary current along the northern coast of Honshu, mixing with the coastal waters along the journey.

Core surface water (Tsb): It originates in a branch of the Tsushima Warm Current which, upon entering through the West Channel into the Sea of Japan, undergoes meanders before approaching Honshu from off Sado Island toward Cape Nyudo-zaki. This water, located just outside the Tsc, exhibits little influence from other water masses in the Sea of Japan. It is also located around the axis of the Tsushima Warm Current.

Cold-current mixed surface water (Tsl): This originates from yet another branch entering the West Channel of the Tsushima Strait which separates from the Tsb to move northward along the east coast of Korea. In the process, it mixes with the cold surface water of the Sea of Japan along the so-called polar front. It rejoins the remainder of the Tsushima Warm Current between Iwasaki and the entrance to the Tsugaru Strait. This water is otherwise known as East Korea Warm Current (Uda, 1934).

Tsushima Warm Current mid-water (Tm): This water is the principal component of the Tsushima Warm Current, with its center located between 50 and 75 m below the surface usually beneath the Tsb.

Liman Cold Current surface water (L): This is the surface water of the Liman Cold Current characterized by low salinity, low temperature and high nutrient salts.

Japan Sea mid-water (M): In the Tsushima Warm Current region, this water has its center around 200-250 m below the surface. It tends to subside from offshore toward the lower boundary of the Warm Current.

Japan Sea deep-water (B): This water constitutes the original water of the Sea of Japan along with the Japan Sea bottom water (B). It is generally located deeper than about 400 m from the surface beneath the Warm Current. Temperature, usually less than 1°C, decreases with depth.

Japan Sea bottom water (B): This is located deeper than 1,000 m, and is part of the original water of the Sea of Japan.

A schematic representation of water mass stratification adjacent to the coast is shown in Figure 4-23. Figure 4-24 shows a T-Cl diagram for the various water masses. It is recognized that the water masses can be readily identified by characteristic sigma-t values consistent with the order of stratification. Namely, the Tm is characterized by a sigma-t value of 25.50, the M by 27.00, and the D by 27.30.

In order to examine the transition of stratification in the Tsushima Warm Current between the south and the north of the entrance to the Tsugaru Strait, Figure 4-25 presents two T-Cl sections, one off Gongen-zaki (41°10'N, 12 km south of Tappi-saki) and the other off Esashi (41°50'N). It is readily seen that, across the entrance to the Tsugaru Strait, the Tsushima Warm Current, identified by a sigma-t value of 25.50, has diminished considerably, whereas the water mass stratification below a sigma-t 26.50 remained virtually unchanged.

Figure 4-26 shows T-S diagrams for March, May, July and September at three locations: off Iwasaki, off the Tsugaru Strait west entrance, and off Esashi (41°50'N). It is mentioned that a sigma-t value of 26.5 may be used as an indicator of the lower limit of the mid-water in the Tsushima Warm Current in summer (Akagawa, 1954).

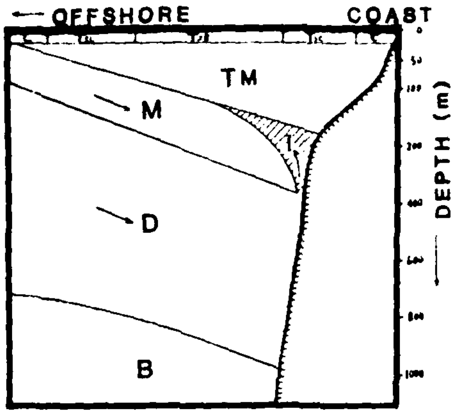


Figure 4-23. Schematic distribution of characteristic water masses in the inflow region to the Tsugaru Strait.

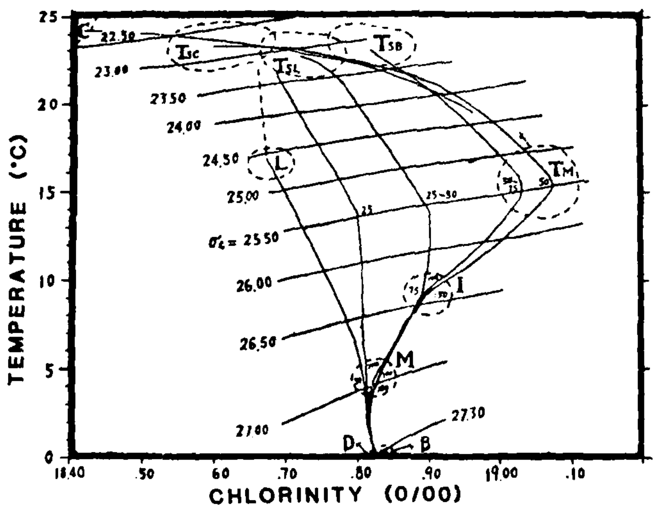


Figure 4-24. T-Cl diagram of characteristic water masses in the inflow region to Tsugaru Strait.

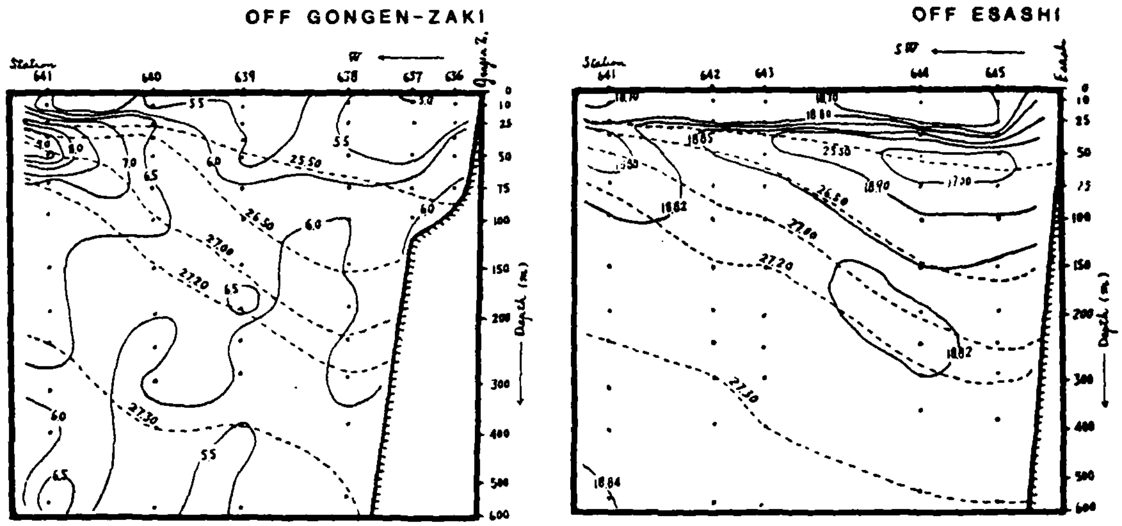


Figure 4-25. T-Cl distributions off Gongen-zaki and Esashi.

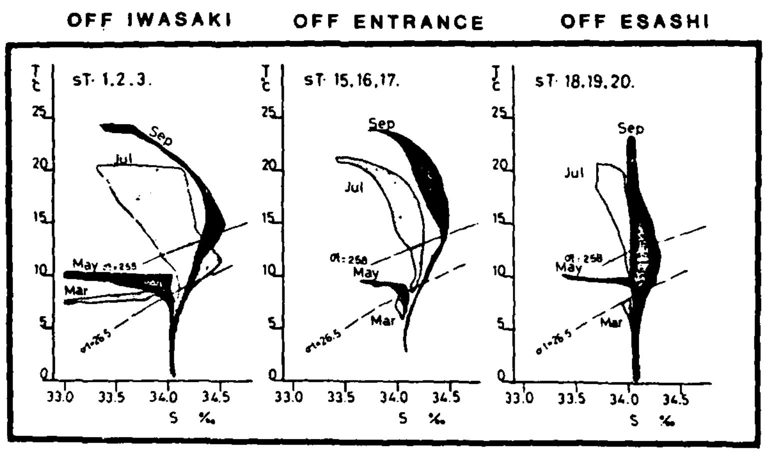


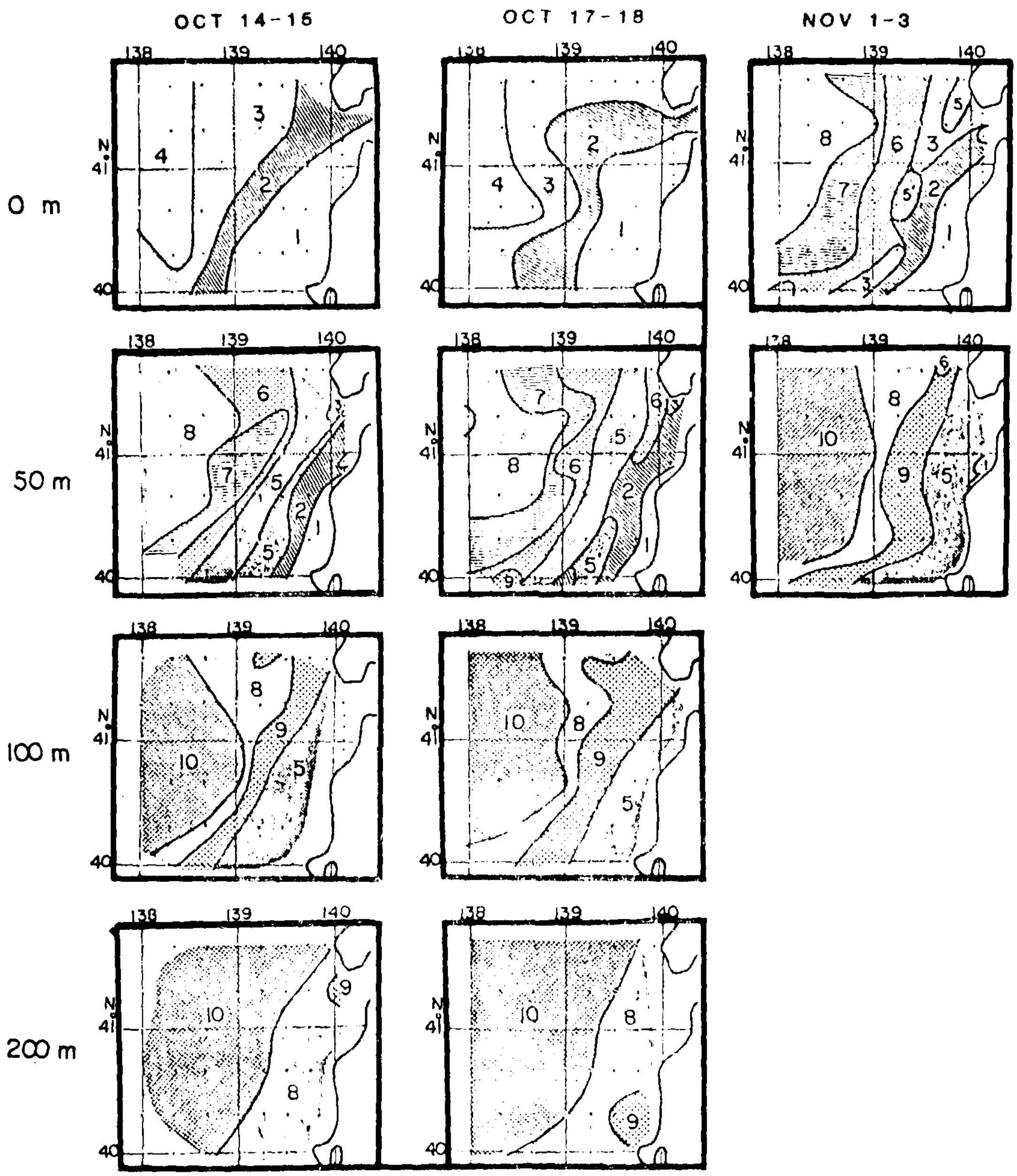
Figure 4-26. T-S diagrams March - September for the approach, the entrance and the Hokkaido sides of Tsugaru Strait.

In March, the convective cooling and consequent mixing during the winter months have caused the water in the Tsushima Warm Current to gain in sigma-t to 26.5 - 26.8, with temperatures around 6 - 8°C and salinities around 34.0 PPT. It is noticed that during this month, a water with a sigma-t value less than 26.5 is virtually absent. In July, a high salinity water with salinities higher than 34.2 PPT made appearance in the mid-water of the Tsushima Warm Current. This water, with temperatures 13 - 17°C, salinities 34.2 - 34.3 PPT and sigma-t values 25.0 - 25.8, is very likely a fresh inflow into the Sea of Japan through the Tsushima Strait for the season. However, during this month, a water with salinities higher than 34.2 PPT and sigma-t values lower than 25.8 is missing off the west coast of Hokkaido, suggesting that during this time the fresh inflow into the Sea of Japan arriving here is being entrained into the Tsugaru Strait in its entirety. In September, a water characteristic of the mid-water of the Tsugaru Warm Current makes a gradual appearance off Hokkaido, with salinities 34.2 - 34.3 PPT and sigma-t values 25.1 - 25.8. During this month, the Tsushima Warm Current spills most of its transport into the Tsugaru Strait and releases only a small portion toward the west coast of Hokkaido. The water mass off the west coast of Hokkaido during this month is still dominated by a water with sigma-t values higher than 25.8 which has been formed in the Sea of Japan.

Figure 4-27 shows water mass distributions from the JMO data between October 14 and November 3, 1970 (Science and Technology Agency, 1971). Relative to Akagawa's notation, the following correspondance may be noted:

(1) - C
(2) - Tsc and TsB
(3) - Tsl
(4) - L
(5), (5') - Tm
(7), (8) - M
(9) - Tm
(10) - B

It can be seen that the Tsushima Warm Current surface water to a depth of 50 m flows into the Tsugaru Strait in its entirety, but that the Tsushima Warm Current mid-layer water would tend to bypass the entrance to move northward toward Hokkaido at a 50-meter level while being entrained into the Strait in substantial amounts at a 100-meter level.



(1) Coastal water. (2) Tsushima Warm Current at surface.
(3) Mixed surface water. (4) Original cold surface water.
(5) Tsushima Warm Current mid layer. (5') Tsushima W.C. mid-layer family. (6) Mixed mid-layer. (7) Cold mid-layer.
(8) Japan Sea mid-water. (9) Tsushima W.C. lower water.
(10) Japan Sea original water.

Figure 4-27. Water mass distribution off the entrance to Tsugaru Strait.

Drift bottle studies also bear out the tendency that the currents are entrained into the strait in accordance with the characteristic behaviors and distributions of individual water masses. Figure 4-28 lists the results of drift bottle study by Akagawa (1955) and those by a JMA 5-ship operation during October-November, 1970. In the experiment by Akagawa, the bottles which drifted into the strait channel originated from the locations of water masses C, Tsb and Tsc, the rest bypassing the entrance to move northward. In the JMA experiment, a comparatively larger number of bottles washed up on the west coast of Hokkaido north of the Tsugaru Strait as they were released further offshore from the coast. Percentage of the number of bottles found on the Hokkaido coast to the total recovered number for each individual release point was, from coast to offshore, 0% (Chofu Maru, closest to shore), 13% (Seifu M.), 14% (Ryofu M.), 9% (Kofu M.), and 9% (Shumpu M.). Of a total of 151 bottles recovered, 45 bottles were found on the west coast of Hokkaido, representing about 30%.

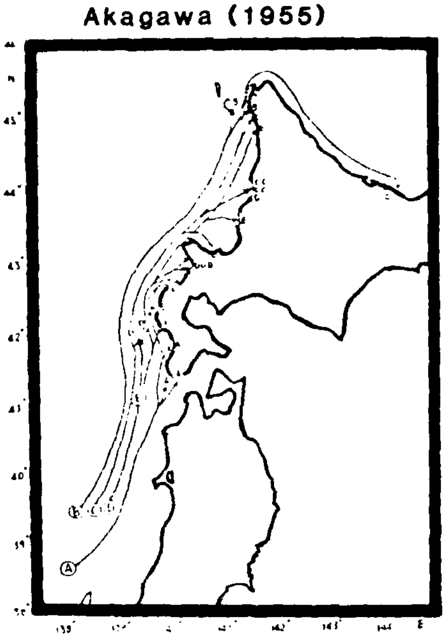
Recently, Conlon (1981) investigated the dynamics of the inflow processes at the Tsugaru Strait by conducting a detailed analysis of steric sea levels in the adjacent waters. Figure 4-29 shows his results of steric height variations based on the JMA 5-ship operation in October and November, 1970. One can see that there is a meridional drop in steric height along the coast from the south to the north toward the western entrance. The volume transport of the influx into the Tsugaru Strait (T) exhibited a high correlation with the meridional drop in sea level (h), i.e.

$$T\ (\mathrm{Sv}) = 7.85 \times 10^{-2}\ h(\mathrm{cm}) + 0.30 \quad (r = 0.98)$$

Based on this relationship, he concluded that volume transport into the strait was associated with a "relaxation" of setup induced by the Tsushima Warm Current in the vicinity of the Tsugaru Strait.

Channel Dynamics

Volume transport through the Tsugaru Strait has been variously estimated. Miyazaki (1952) estimated it to be 0.4 - 1.3 Sv. Yasui and Hata (1962) proposed a transport range of 1 - 4 Sv. Hata (1973)



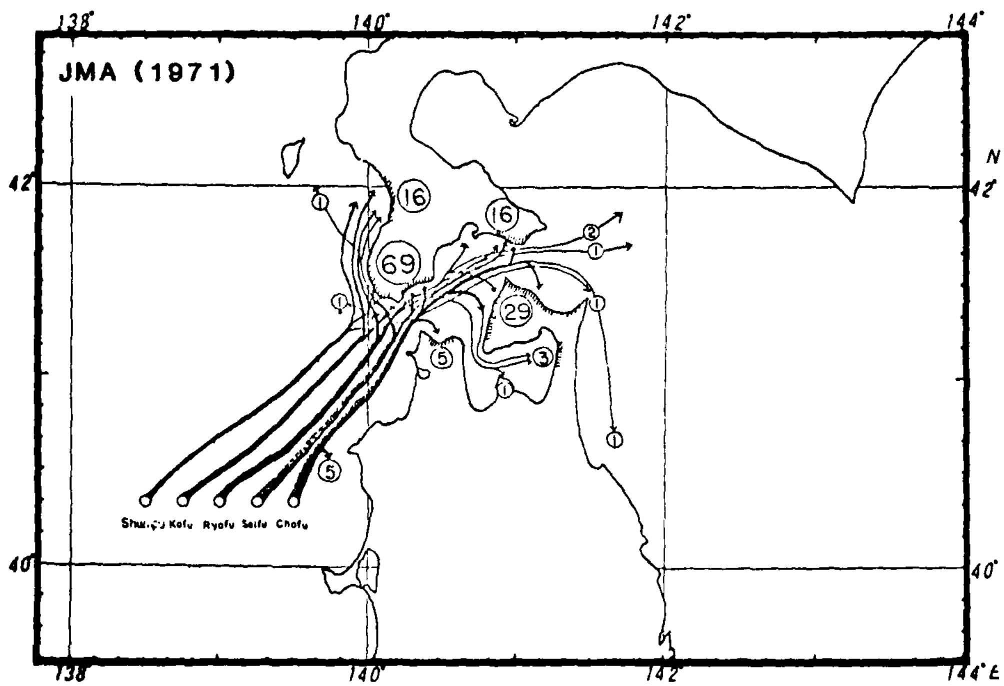


Figure 4-28. Drift bottle trajectories.

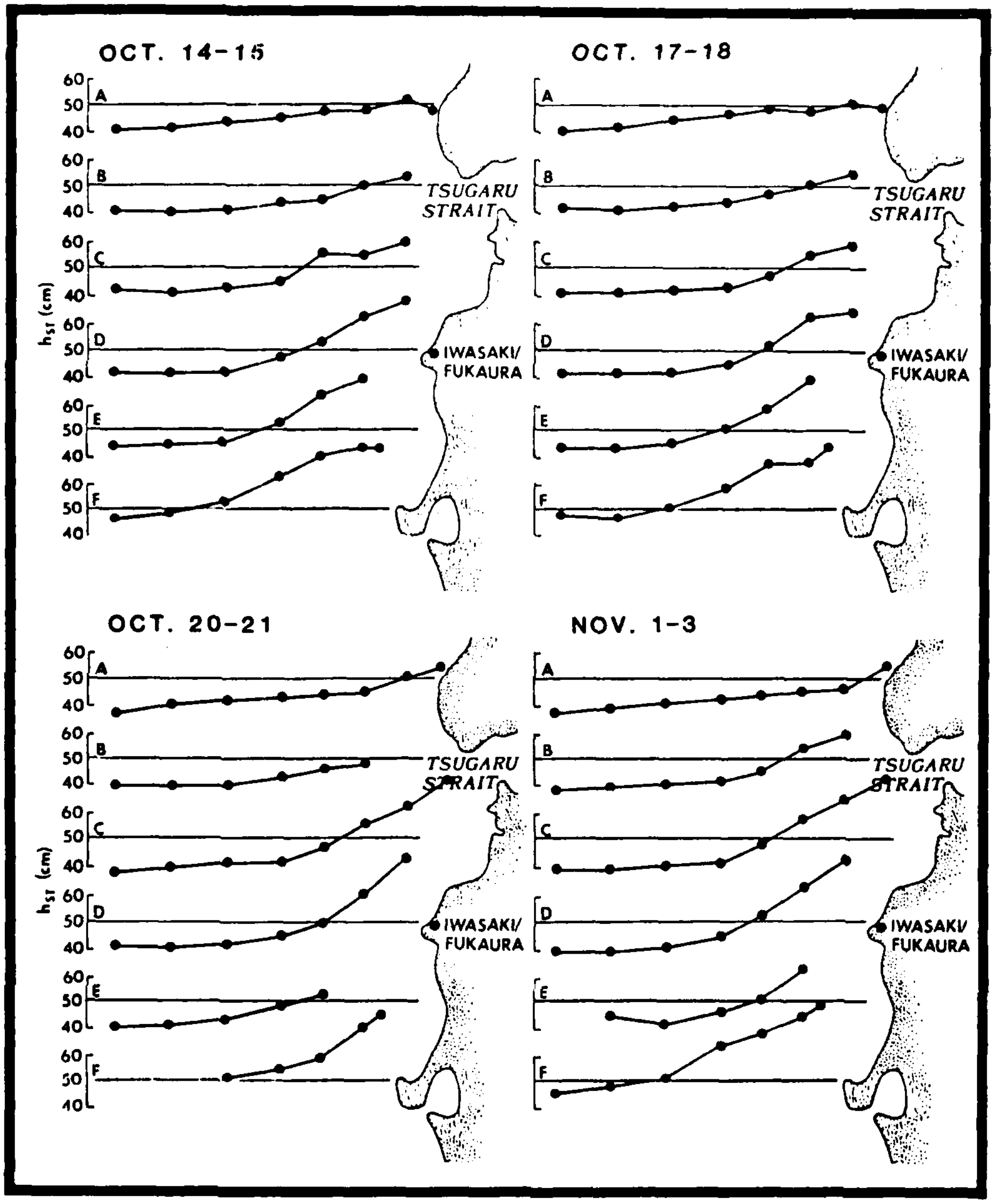


Figure 4-29. Steric height distribution in the entrance region to Tsugaru Strait.

indicated a seasonal fluctuation ranging from 1.7 Sv in winter, 1.8 Sv in spring, 4.4 in summer to 4.0 in fall. During four consecutive surveys made over a two-week period between October 13 to November 3, 1970, two sets of closely agreeing transport values of 1.6, 1.5, 1.8 and 1.6 Sv (Conlon, 1981) and 1.8, 1.4, 1.7 and 1.5 Sv were reported (Science and Technology Agency, 1971).

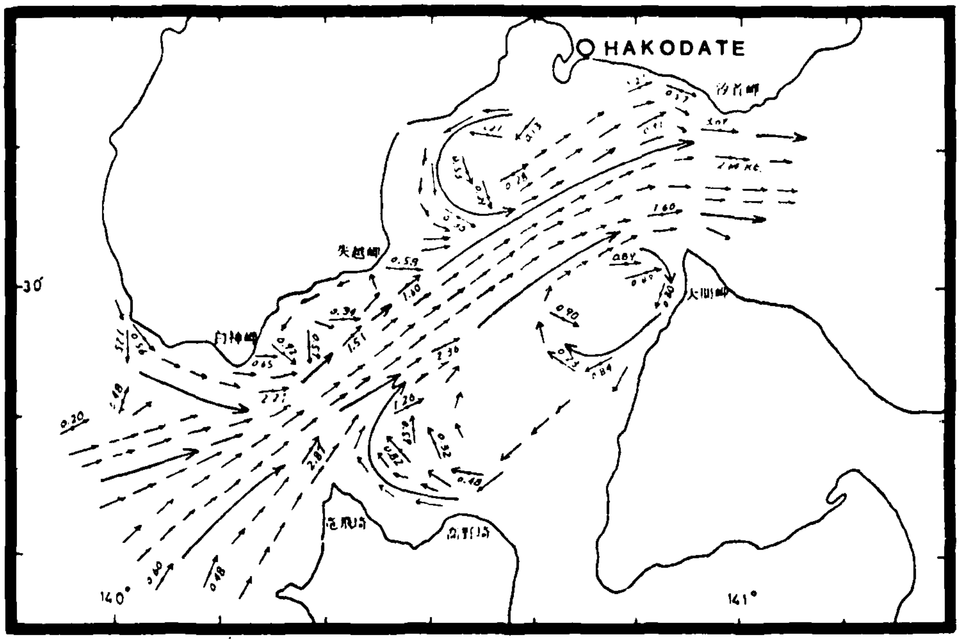
The flow field in the channel has been studied by a number of investigators, among them Suda et al. (1932), Hikosaka (1953), Hata (1973), and more recently the JHO (Science and Technology Agency, 1971 and 1979) and Conlon (1981). It is known from these and other studies that the current in the channel forms a core only about 20 km wide, flanked on both sides by sidewall eddies which are topographically trapped due to the configuration of the channel boundary. Maximum speeds occur during the spring phase in summer and winter, attaining as much as 4.5 - 5.5 knot at the western entrance and 5.2 - 6.2 knot at the eastern exit. These maximum speeds are directed to the east due to the superimposition of tidal and ocean currents, and are usually higher on the south than on the north sides of the core.

Figure 4-30 shows the measurements of non-tidal currents during the July-November period in 1970, 1975, 1976 and 1977 by the JHO.

The harmonic constituents of tidal currents in the Tsushima Strait have been well established through repeated studies by the JHO. Table 4-3 shows harmonic constituents determined from the recent JHO study (Science and Technology Agency, 1979). (See Figure 4-30 for the exact location of the stations). It can be seen that the dominant component is K1 tide, followed by M2 and S2 in the order named. Non-harmonic (ocean current) terms are also indicated, which range between about 1.7 and 2.6 knot.

Conlon (1981) investigated momentum balance for the ocean current in the channel to find that the principal balance within the core current is likely to be between the pressure gradient term and the vertical Ekman term. His analysis further indicated that the longitudinal barotropic gradient is balanced mainly by the longitudinal baroclinic pressure gradient and friction. The longitudinal Ekman term was found negligible, whereas the lateral Ekman term played some role in the region of the sidewall eddies, but not significantly within the core itself.

AUG.-OCT. 1970



JULY-NOV. 1975, 76, & 77

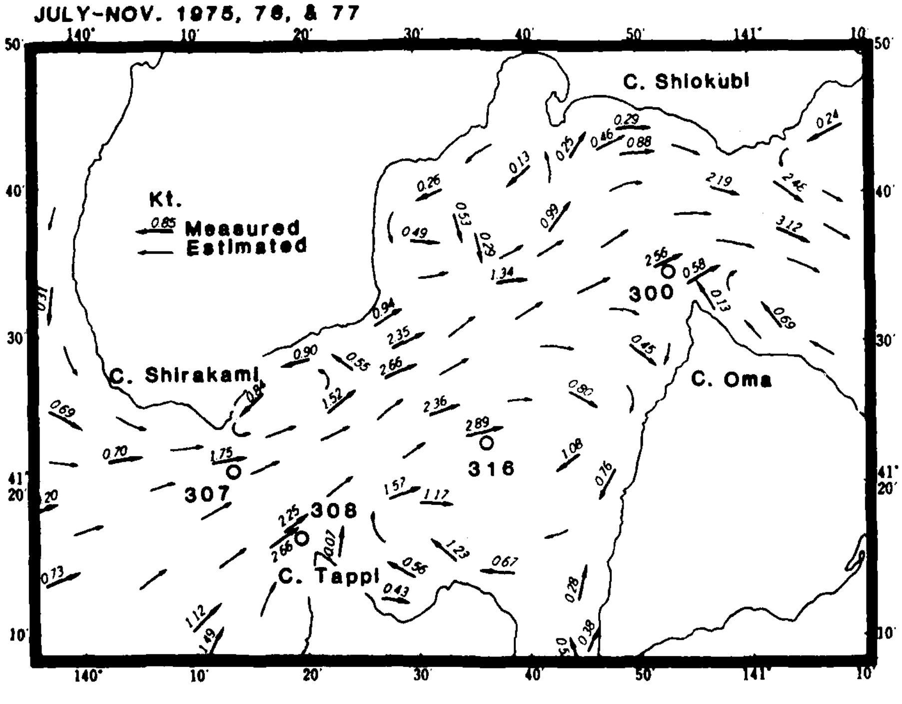


Figure 4-30. Non-tidal currents in the Tsugaru Strait.

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TABLE 4-3. Harmonic components of tidal currents in the Tsugaru Strait. (S.T.A., 1979)

STATION	COMPONENT		M_2	S_2	K_2	N_2	K_1	O_1	P_1	Q_1	M_4	MS_4	S_0	NON-HARMONIC
316	N(+)	V	0.344kt	0.116kt	0.032kt	0.132kt	0.295kt	0.270kt	0.098kt	0.213kt	0.126kt	0.112kt	0.791kt	
		K	25°	62°	62°	246°	246°	191°	246°	49°	348°	13°		74°
	E(+)	V	0.178	0.187	0.051	0.234	0.679	0.730	0.225	0.321	0.029	0.074	2.780	2.890kt
		K	198	130	130	43	128	94	128	311	156	149		
	AXIS	V	0.260	0.172	0.047	0.257	0.694	0.717	0.230	0.323	0.060	0.095	−2.483	
		K	20	319	319	226	303	269	303	122	342	341		
300	N(+)	V	0.164	0.187	0.051	0.144	0.666	0.403	0.221	0.355	0.116	0.052	1.071	
		K	306	45	45	350	346	38	346	297	323	3		65°
	E(+)	V	0.591	0.213	0.058	0.091	1.475	1.156	0.489	0.234	0.037	0.064	2.324	2.559kt
		K	318	6	6	50	30	12	30	14	102	58		
	AXIS	V	0.610	0.253	0.069	0.119	1.558	1.212	0.516	0.274	0.026	0.072	2.551	
		K	317	15	15	29	25	15	25	348	22	46		
307	N(+)	V	0.473	0.188	0.051	0.282	0.399	0.240	0.132	0.046	0.019	0.031	0.359	
		K	355	110	110	322	292	241	292	250	239	331		78°
	E(+)	V	0.562	0.134	0.037	0.084	1.135	0.711	0.376	0.358	0.043	0.045	1.709	1.747kt
		K	28	37	37	17	43	24	43	36	53	318		
	AXIS	V	0.604	0.141	0.038	0.105	1.112	0.684	0.369	0.351	0.041	0.049	1.739	
		K	25	46	46	2	40	23	40	36	53	319		
308	N(+)	V	0.352	0.149	0.041	0.220	0.492	0.535	0.163	0.120	0.026	0.031	1.309	
		K	45	81	81	51	48	17	48	28	16	131		54°
	E(+)	V	0.791	0.349	0.095	0.266	0.927	0.931	0.307	0.266	0.016	0.012	1.828	2.248kt
		K	0	55	55	311	44	20	44	354	302	260		
	AXIS	V	0.829	0.373	0.102	0.242	1.048	1.071	0.347	0.285	0.021	0.011	2.215	
		K	7	59	59	334	45	19	45	0	334	183		

Time of Survey: 316: Jul 18-Aug 1, 1977 300: Oct 28-Nov 11, 1975
307: Sep 12-Sep 26, 1976 308: Sep 11-Sep 25, 1976

Tsugaru Current Extension

The Tsugaru Warm Current expands into the Pacific Ocean after exiting through the eastern opening between Shiokubi-zaki and Shiriya-misaki. (See Figure 4-31) The expansion generally becomes conspicuous in May, attains a peak intensity around August, and decreases toward fall and winter. It is also generally recognized that the outflow of the Tsugaru Warm current exhibit a greater degree of secular fluctuation than the Tsushima Warm Current approaching the western entrance of the strait. The water mass entering the western entrance appears to take about a month to reach the eastern outlet, as has generally been revealed from water mass analysis (Science and Technology Agency, 1979). Figure 4-32 shows frontal configuration of the expansion of the Tsugaru Warm Current off the eastern exit during October and November (Science and Technology Agency, 1971).

In terms of water mass characteristics, the water at the eastern opening exhibits consistently higher temperatures and higher salinities on the Honshu side, whereas the western entrance is characterized by higher temperatures and lower salinities on the Honshu side and lower temperatures and higher salinities on the Hokkaido side during March and July, and by higher temperatures and higher salinities on the Honshu side beginning in October. The outflowing Tsugaru Warm Current is typically deeper on the Honshu than on the Hokkaido sides.

Conlon (1981) was able to provide an interesting insight into characteristic behaviors of the outflow expansion. It appears that the outflow undergoes an extensive anticyclonic gyral motion during the time of strong transport, and a behavior as a boundary current during the time of weak transport. (Figure 4-24) These distinct behaviors, named, respectively, "gyre" mode and "coastal" mode, appeared to alternate depending upon the internal Rossby radius of deformation. The phenomenon was previously modelled in a rotating basin by Whitehead and Miller (1979). As the Rossby radius was progressively increased, the outflow transformed from a narrow jet hugging the right-hand wall to a gyral circulation. Conlon's computation indicated that an internal Rossby radius of deformation would average about 14 km in the outflow region, but that it would fluctuate from a low of about 4.7 km in February and March to a high of 23.7 in September, indicating that the alternation between gyral and coastal modes may take place as a seasonal phenomenon: a gyre mode during summer and fall, and a coastal mode during winter and spring. Dynamic calculations relative to a 500-db level on the basis of 6 series of JMA serial observations during

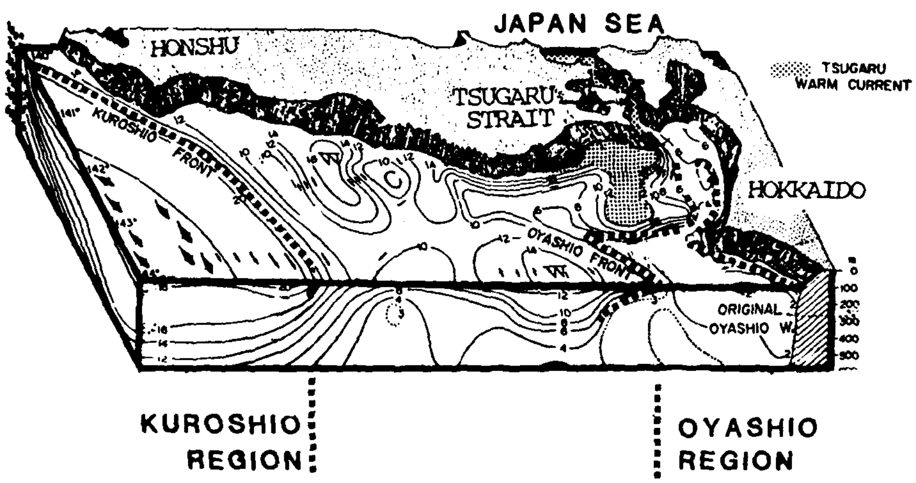


Figure 4-31. Schematic view of the region of Tsugaru Warm Current extension.

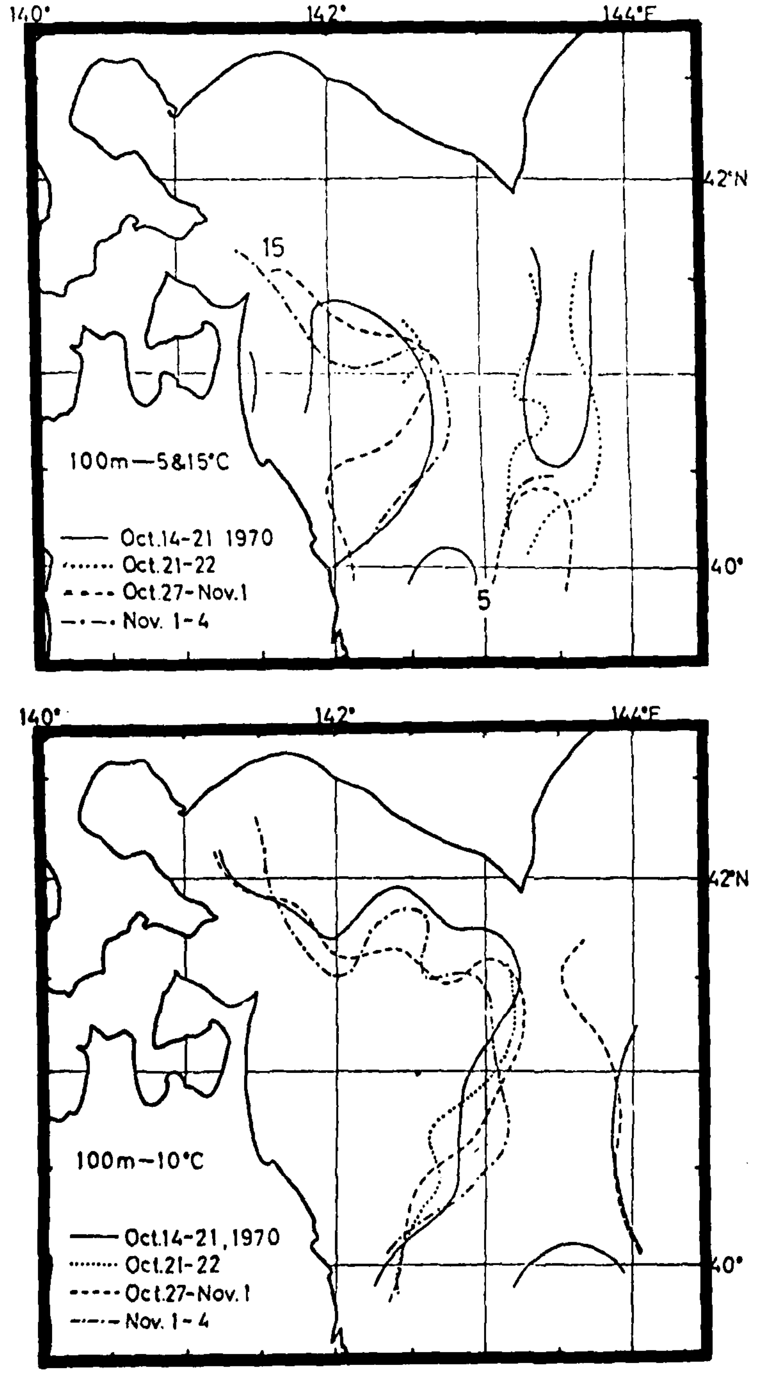


Figure 4-32. Various observed patterns at the front of the Tsugaru Warm Current Extension.

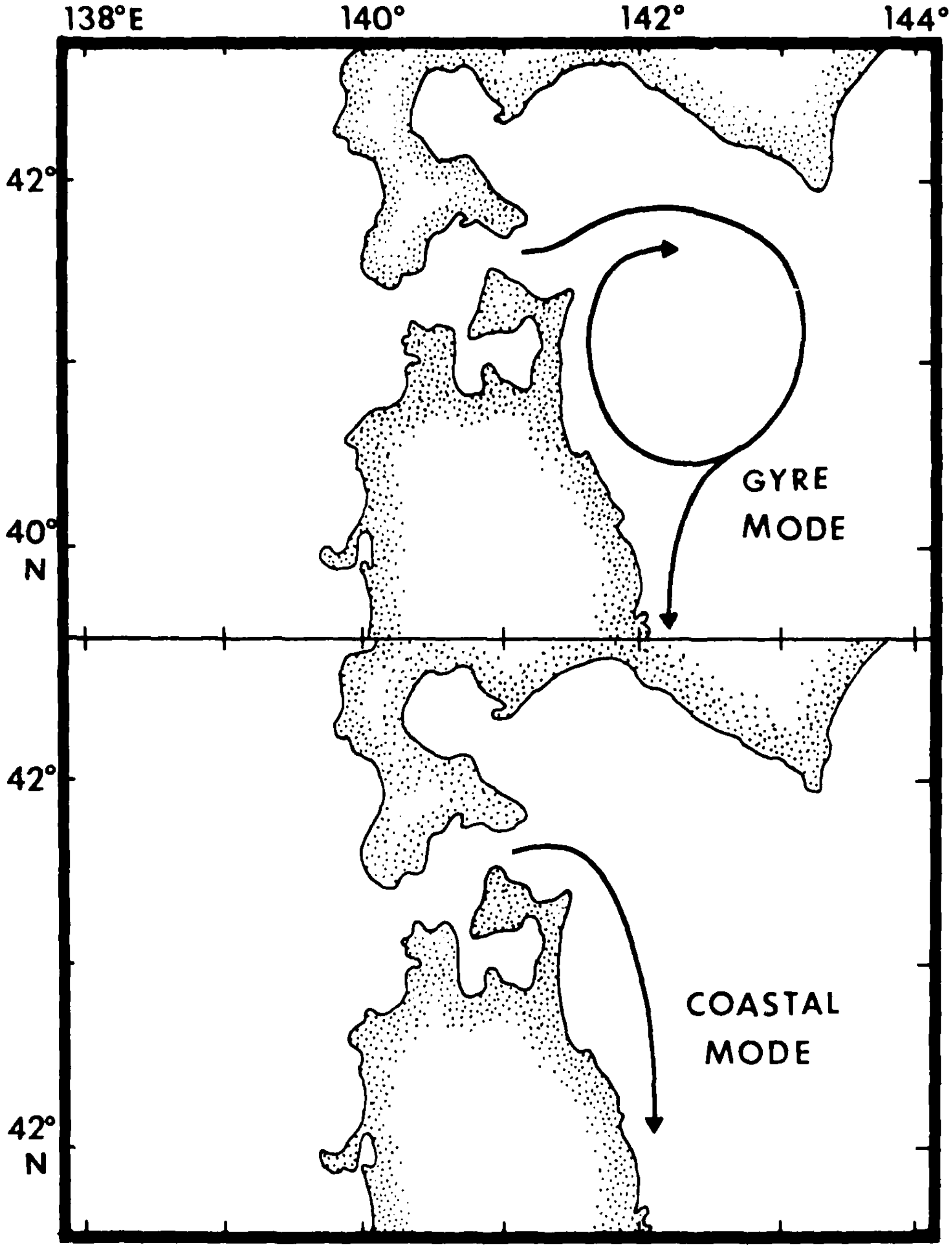


Figure 4-33. Schematic representation of "gyre" and "coastal" mode. (Conlon, 1981)

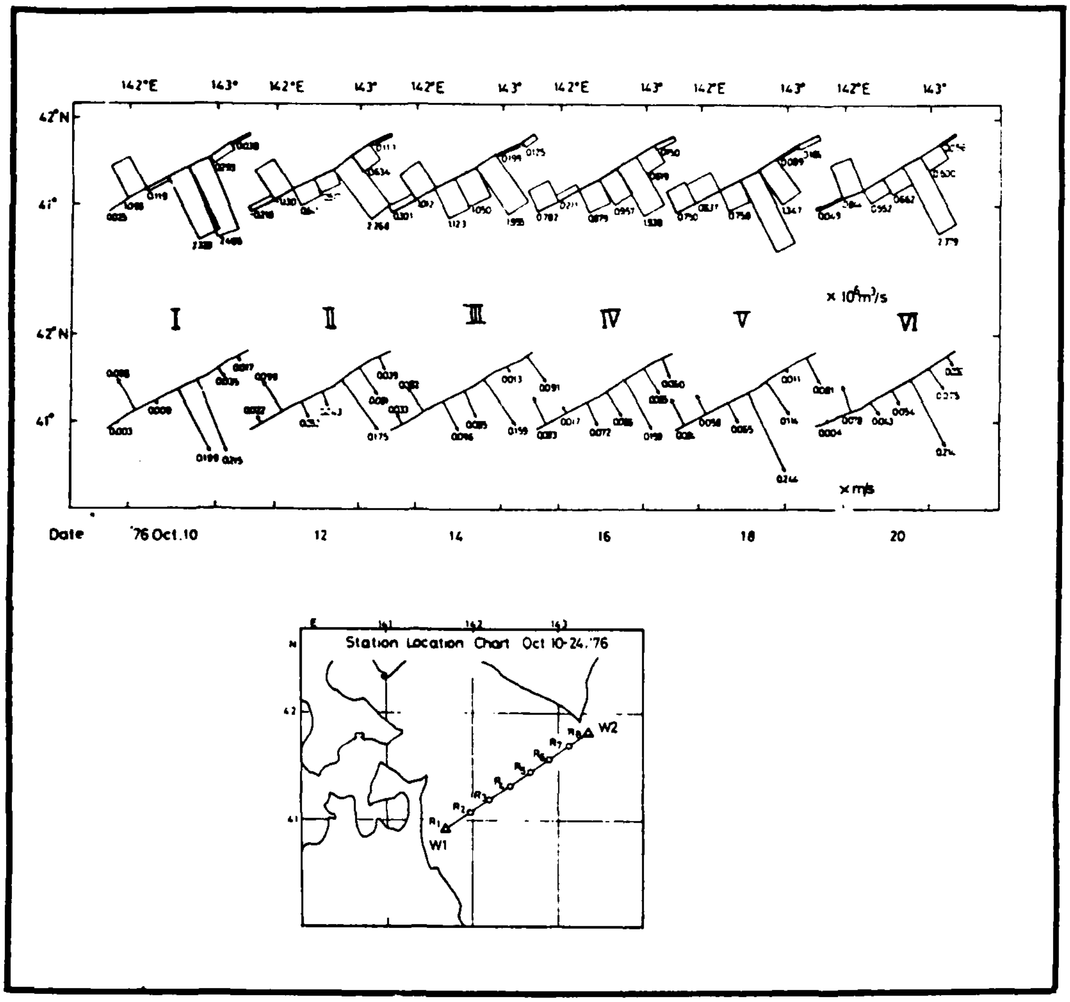


Figure 4-34. Gyral motion at the extension of Tsugaru Warm Current (S.T.A., 1979)

October 10 through 20, 1976 in the outflow region, shown in Figure 4-34, also indicate a persistence of anticlockwise motion over a 10-day period of the survey (Science and Technology Agency, 1979).

4.3 Soya Strait

Overview of Problems

Major attention of Japanese oceanographers on the Soya Strait has been directed to the region of the Soya Warm Current region along the northern coast of Hokkaido east of the Soya Strait. This area represents one of the most productive coastal fishing grounds in Japan, and the presence of drifting ice poses serious threat to coastal shipping. On the other hand, the degree of attention being paid to the strait itself as well as the inflow region has been modest by comparison.

Studies of the inflow and the flow dynamics in the strait region are hampered particularly by the fact that Japanese cruises rarely venture out beyond the half-way point to the U.S.S.R. territory of Sakhalin and the Maritime Provinces. The situation seems to be mitigated somewhat by the increasing use of satellite remote-sensing imagery in recent years. An example of very effective use of TIROS-N imagery covering the entire Soya Strait region has recently appeared in a Government-sponsored report: Report of Comprehensive Study of the Sea of Okhotsk (Science & Technology Agency, 1981).

The inflow dynamics at the Soya Strait essentially remains an unresolved problem. The prevailing notion is that the Tsushima Warm Current approaching the Soya Strait along the west coast of Hokkaido, forming a narrow boundary current, makes a sharp turn (of an almost 120°) into the Soya Strait. Evidence indicates that the turning maneuver of the Tsushima Warm Current at the Soya Strait is a much more complex process involving a series of interactions between the approaching Tsushima Warm Current and the water in the Tartar Strait. The writer's tentative

interpretation of this process based on the existing cruise data and the recent TIROS-N imagery, is presented in this chapter. The 1942 cruise of Yushio Maru of the Hakodate Marine Observatory was one of the few cases in which the data was taken over an extensive area in this region. This data is described in detail.

Inflow

Figure 4-35 shows major topographic features with bathymetry in the vicinity of the Soya Strait. The Soya Strait is about 43 km wide at its narrowest cross-section between Cape Krilion and Cape Soya where the water depth goes down to only about 74 meters (Defense Mapping Agency Hydrographic Center, Chart No. 96938: Soya Kaikyo). For about 30 km on either side of the strait, the water depth is shallower than 100 meters. On the west side of the strait, the southerly approach to the strait, between Hokkaido and Okushiri Island, is only 22 km wide with a maximum depth of about 80 meters. In contrast, the northerly approach to the strait, off the west coast of Sakhalin, is free of major obstruction. On the east side of the strait, the channel widens abruptly toward the Sea of Okhotsk, with a gentle slope extending for about 120 km to a depth of 200 meters. Figure 4-36 shows various channel cross-sections in the vicinity of the Soya Strait.

Among the key reasons which account for the complexity of inflow dynamics at the Soya Strait are:

(1) Volume transport of the Tsushima Warm Current approaching the Soya Strait is highly variable, depending not only upon the inherent fluctuation of the transport through the Tsushima Strait but also upon the outflow into the Pacific Ocean through the Tsugaru Strait. Figure 4-37 shows the fluctuation of the northward transport of the Tsushima Warm Current along the west coast of Hokkaido (Hata, 1962). Over a 12-year period between 1947 and 1959, the transport fluctuated between almost 0 to almost 3 Sv, with an average remaining less than 1 Sv. It seldom exceeded 3 Sv. An average 22% of the transport arriving at the Tsugaru Strait moved northward toward the Soya Strait, with a wide range of variation between almost 0 to about 50%.

(2) The Tsugaru Warm Current moving northward to the Soya Strait along the west coast of Hokkaido encounters complex coastline and bottom topography. The coastline irregularity

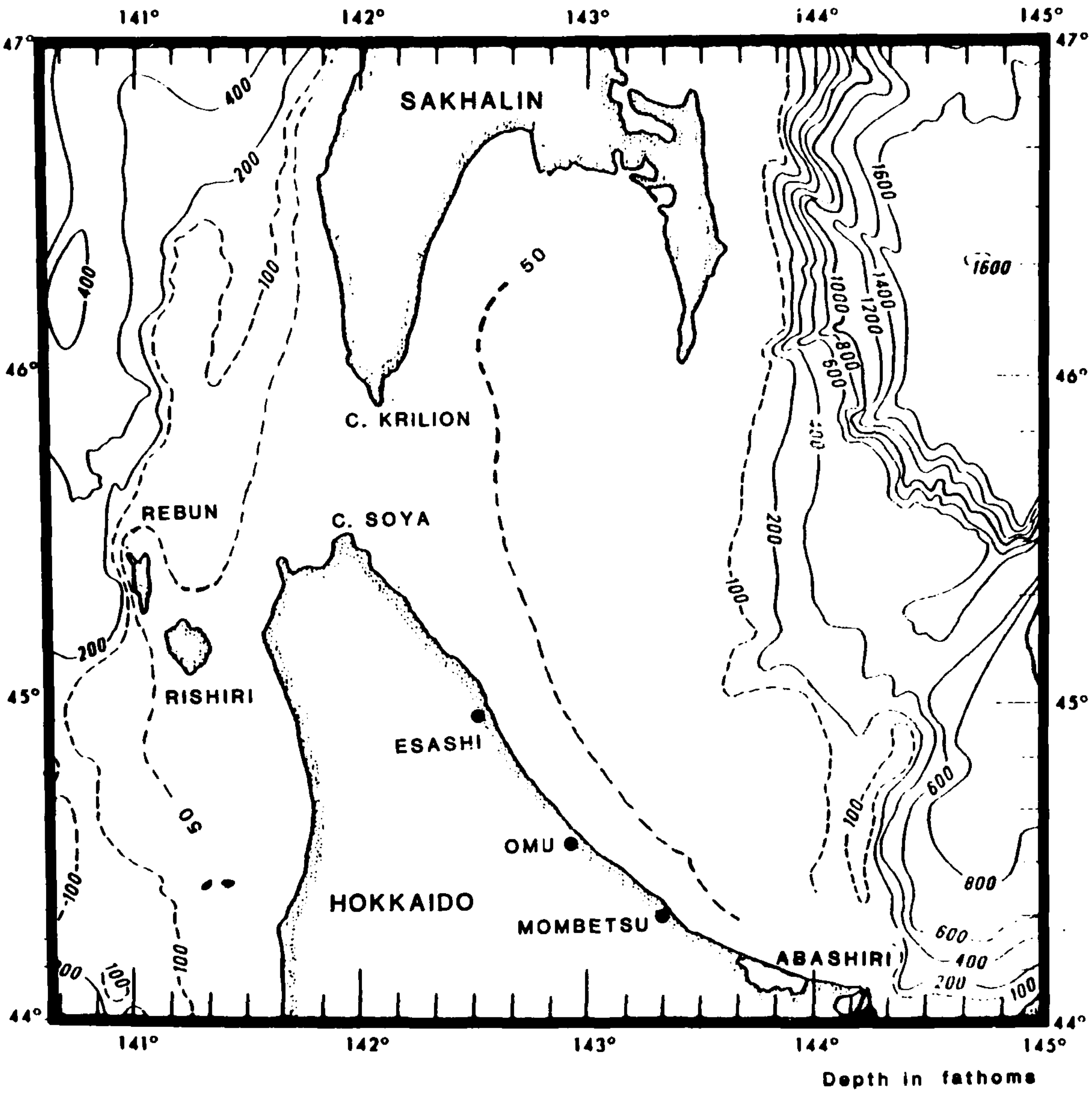


Figure 4-35. Major topographic features in the vicinity of Soya Strait.

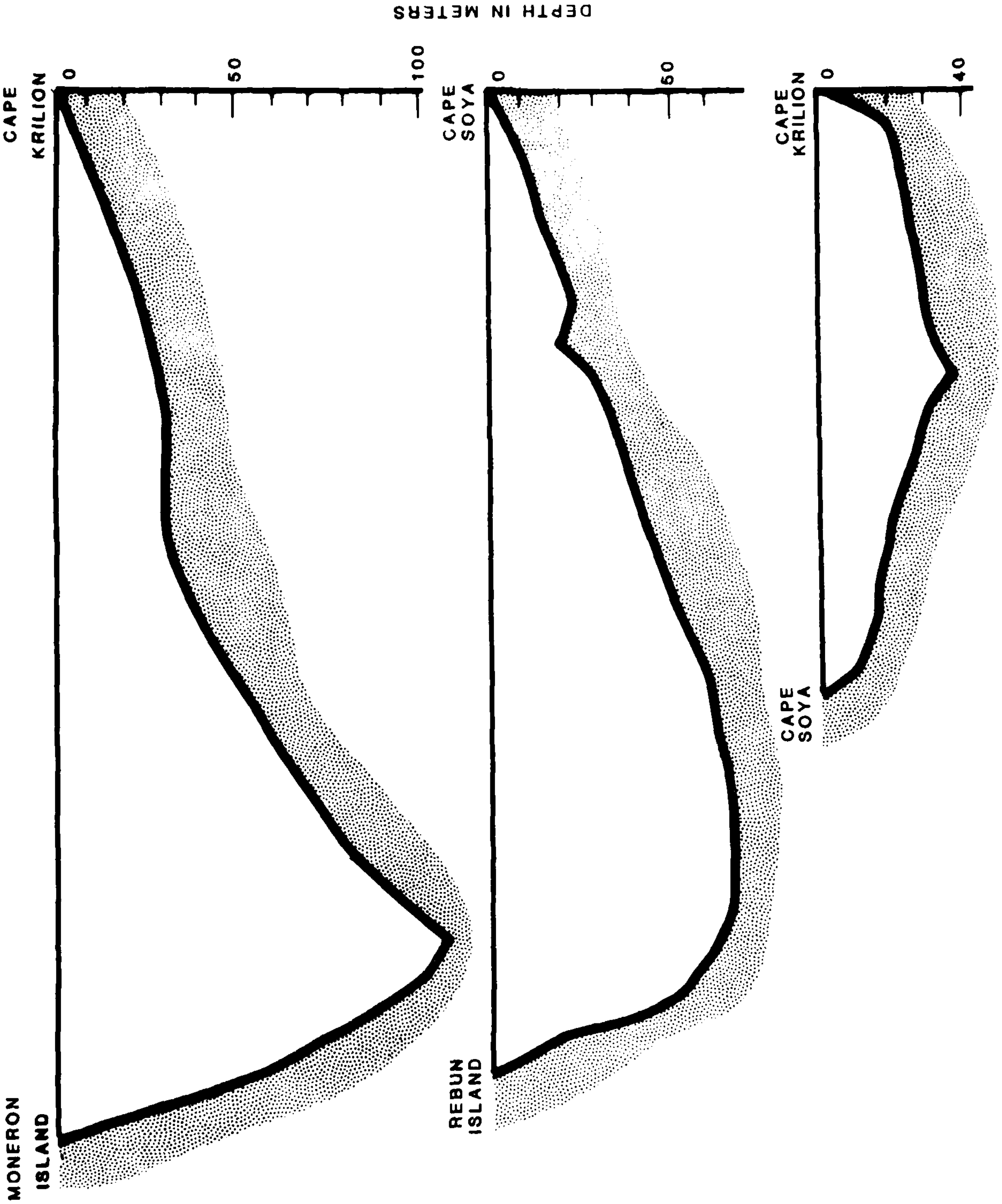


Figure 4-36. Typical cross-sections in the vicinity of Soya Strait.

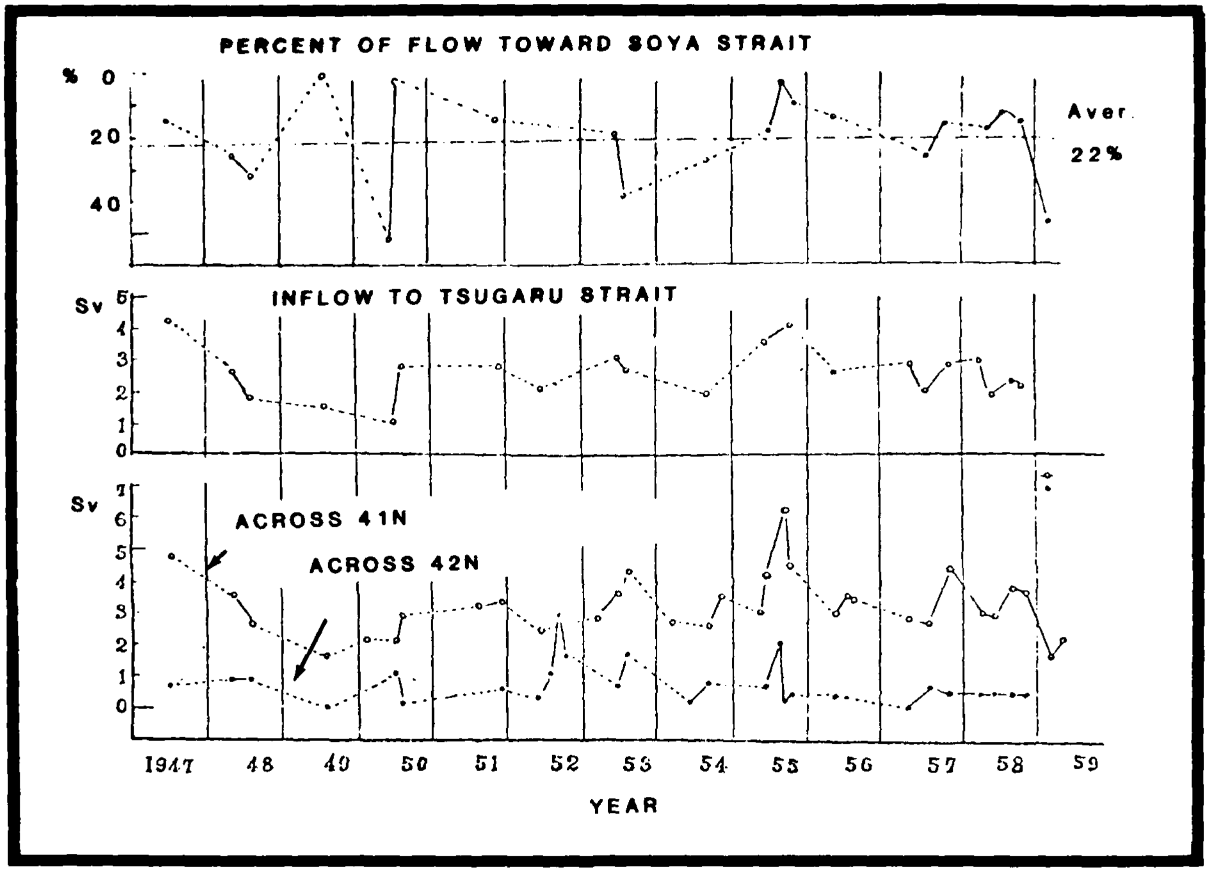


Figure 4-37. Volume transport budget across 41 N and 42 N, Northern Sea of Japan (Hata, 1962).

is particularly severe at Kamoi Misaki. North of this point, the shelf widens abruptly to a broad gentle bottom which extends westward as much as 100 km to a depth of 200 m. This relatively flat bottom would favor instability of a current moving over it, giving rise to a possibility of meander and, in particular, decreased speed. Further north, Rishiri and Rebun Islands lie athwart the approaching current, leaving a narrow channel only about 22 km wide and less than 80 m deep.

(3) As the Tsushima Warm Current moves closer to the vicinity of the Soya Strait, it encounters the Japan Sea Polar Front which persists even during summer in this region. Figure 4-38 shows this situation (JODC, 1978). Hydrography in the northern Sea of Japan, particularly in the vicinity of Sakhalin and the Tartar Strait, is not well understood, and a possible interaction between the encroaching Tsushima Warm Current and a cold water mass typical of this region remains uncertain.

(4) The Soya Strait is closed with ice for at least 3 months of the year. Figure 4-39 shows an example during 1971 (Japan Meteorological Agency, 1972). Although the recent successful measurements of currents under the ice by the researchers of the Hokkaido University's Low Temperature Science Institute demonstrated that the Tsushima Warm Current makes sporadic inflows under the ice (Aota, 1979; Aota and Kawamura, 1979), such inflows would not account for a major amount of transport.

That the Tsushima Warm Current does make an inflow into the Soya Strait, has long been recognized. Drift bottles released in the Tsushima Warm Current south of Hokkaido during summer, when the surface wind affect is least in this area, were found to make occasional landfall on the northern coast of Hokkaido east of the Soya Strait (see Figure 4-40; Akagawa, 1955). However, it is also recognized that the number of bottles recovered east of the Soya Strait was considerably fewer than those found on the west coast of Hokkaido south of the strait.

There are some observations which may shed light on the complex processes of inflow at the Soya Strait. Early in 1933, Suda described that the leading edge of the Tsushima Warm Current would reach as far as the vicinity of the Amur River deep into the Tartar Strait. Although this assertion was made on the basis of few data at that time, a recent study utilizing TIROS-N imagery (Science and Technology Agency, 1981) seems to corrobarate Suda's statement. On the other hand, it has been observed that even during the time of its peak inflow into the

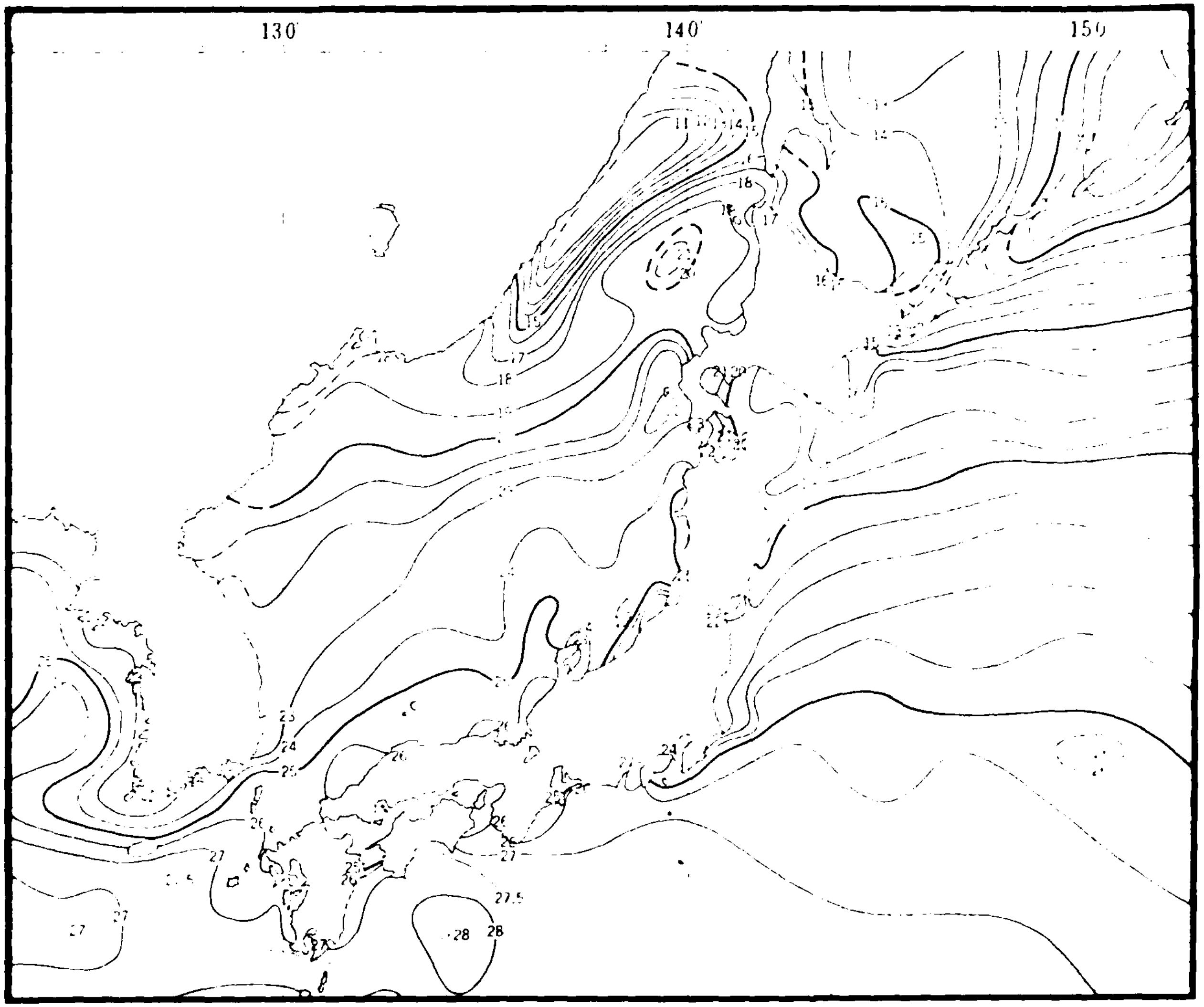


Figure 4-38. Surface temperature distribution in summer in the Adjacent Seas of Japan (JODC, 1978).

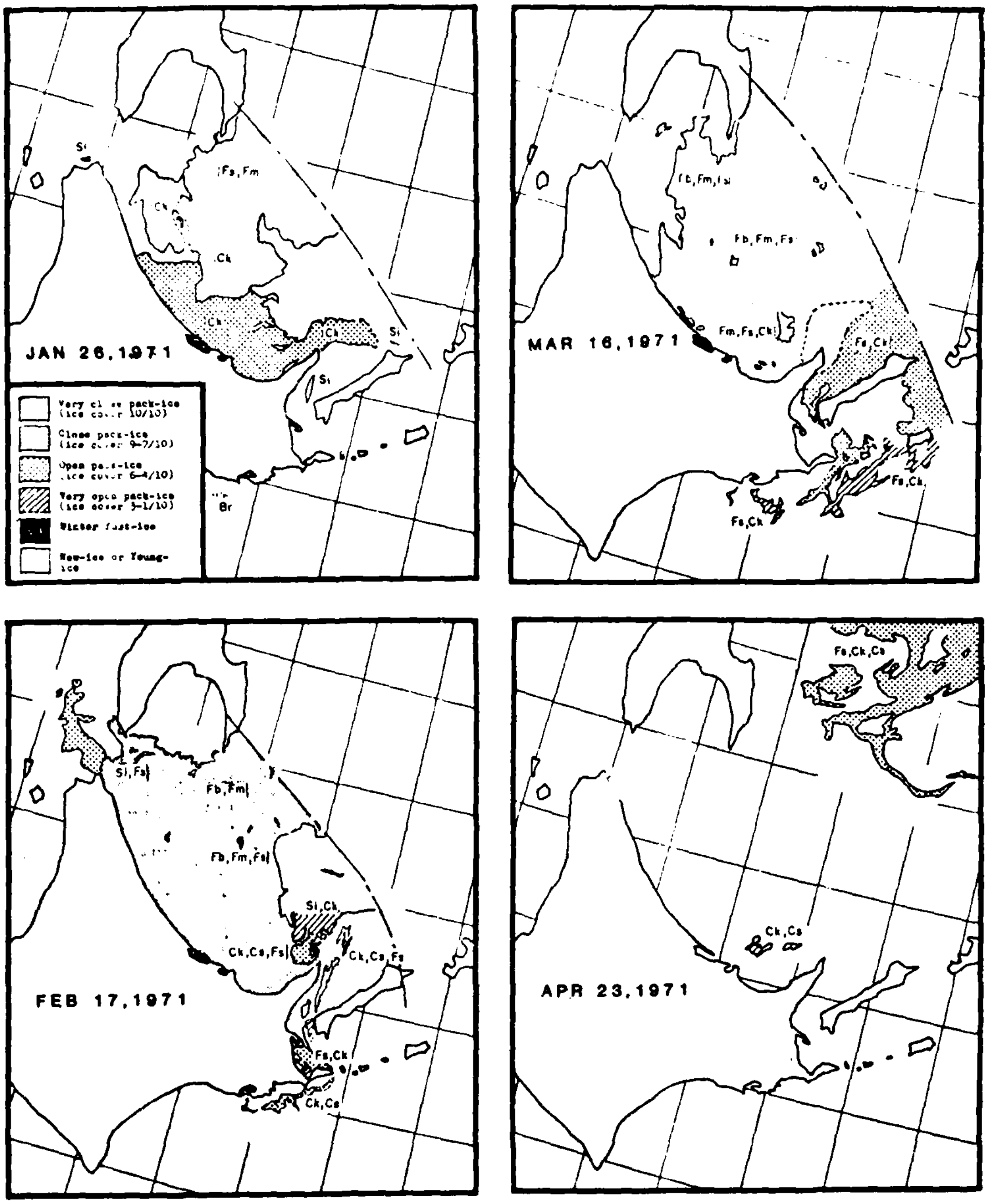


Figure 4-39. Distribution of ice field in the vicinity of Soya Strait, 1971. (JMA, 1974)

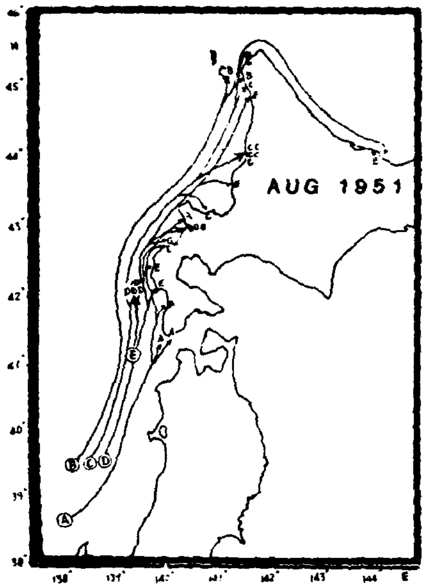


Figure showing the drift bottles' tracks, Aug. 1951

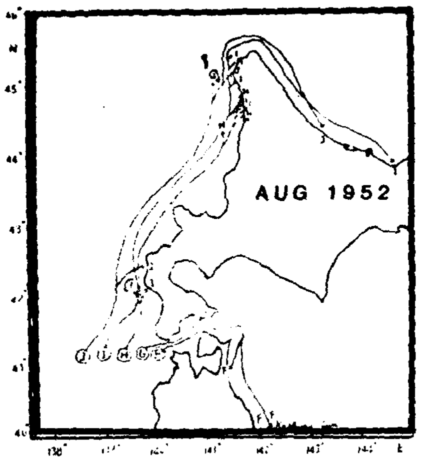


Figure showing the drift bottles' tracks, Aug. 1952

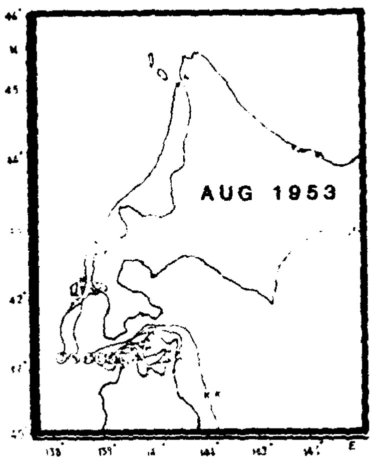


Figure showing the drift bottles' tracks, Aug. 1953

Figure 4-40. Traces of drift bottles in the inflow region to the Soya Strait.

Source: Akagawa, M., 1955: "On the Oceanographical Conditions of the North Japan Sea," Journal of Japan Oceanogr. Soc., 11 (1).

Soya Strait, the Tsushima Warm Current does occupy only part of the strait on the Hokkaido side. The northern part of the strait is usually occupied by a cold water associated with either the Sea of Okhotsk or the Tartar Strait. A sharp front dividing the warm water on the south and the cold water on the north sides has been reported on a number of occasions. Repeated cruises by the Japan Hydrographic Office seemed to find indications that part of the water from the Liman current mixes with the Tsushima Warm Current to flow into the Soya Strait (Japan Hydrographic Office, 1950 and 1952). Recent studies of TIROS-N imagery by Japanese oceanographers (Science and Technology Agency, 1981) have also mentioned frequent occurrences of a front trailing southeast from Cape Krilion, indicating an inflow of cold water which was formed along the southwest coast of Sakhalin.

A set of data taken by Yushio Maru of the Hakodate Marine Observatory provides a unique overview of the complex inflow environment, as the cruise covered a wide spread of stations in the vicinity of the Soya Strait. Yushio Maru's cruise took place during a 22-day period between August 6 and 28, 1942. Although much difficulty was encountered by the ship on its virgin voyage, a wealth of data were collected, and an excellent analysis was published in 1944 (Hakodate Marine Observatory, 1944).

Figure 4-41 shows dynamic depth anomalies computed from the cruise data. Interestingly, the result indicates the presence of a substantial amount of inflow into the strait arriving from the west coast of Sakhalin, a fact which has been recently reconfirmed (and mistakenly called a new discovery) from the study of TIROS-N imagery (Science and Technology Agency, 1981). The result also reveals little indications of inflow from the southerly approach to the strait on the west coast of Hokkaido.

At a 5-m level, the flow pattern is weak except for giving an indication of a cyclonic gyre in the Aniva Bay and an inflow from the northwest into the strait. The gyre and the inflow gave rise to a front which trails in the southeast direction from Cape Krilion. The occurrence of this front has also been recently recognized in TIROS-N imagery by Japanese oceanographers (Science and Technology Agency, 1981). The inflow from the northwest is more conspicuous at a 10-m level, where also the front persists at the same general location. Any indication of an inflow into the strait from the southerly approach is conspicuously lacking.

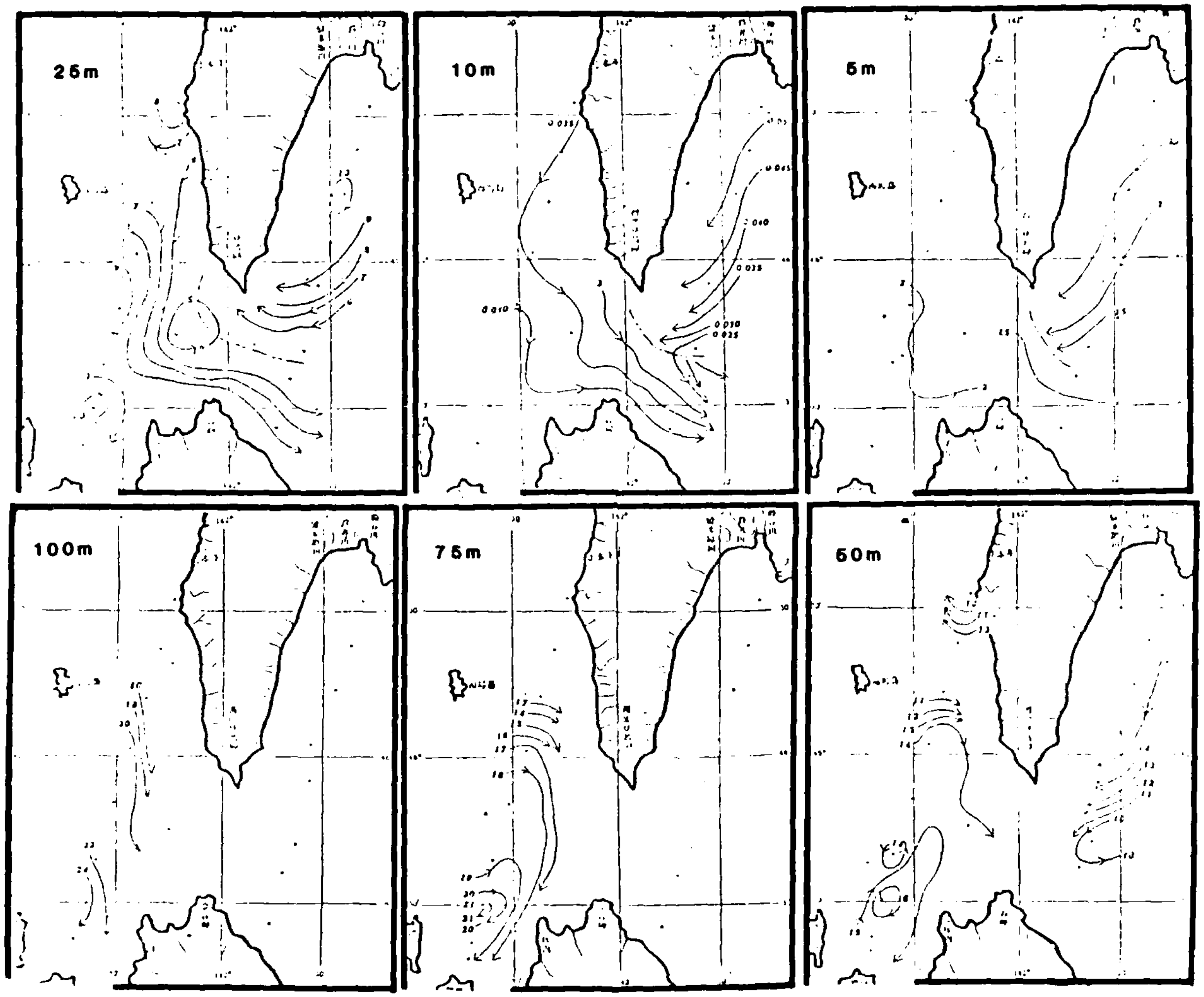


Figure 4-41. Dynamic depth anomalies in the vicinity of Soya Strait in August, 1942. (Hakodate Marine Observatory, 1944)

At a 25-m level, the situation is more or less the same as on the upper layers, except that the front has now shifted southward, pressing the inflow toward the southern half of the strait. At a 50-m level, the inflow has virtually ceased to exist across the strait, which is understandable since the strait is only about 74 meters deep. At this depth, an anticyclonic circulation makes an appearance east of Rebun Island, yielding a southerly flow component away from the strait. At levels deeper than 50 meters, the west side of the strait is completely occupied by southerly currents, and there is no inflow into the strait.

Figure 4-42 shows temperature and salinity distributions at three levels: at the surface, 25 m and 50 m. Figure 4-43 shows two vertical sections on both sides of the strait. Corresponding station locations are indicated in Figure 4-42. At a 25-m layer, temperature is much lower than at the surface. As seen in Figure 4-42, there is a thermocline on this level which rises steeply toward the west coast of Sakhalin, indicating the possibility of upwelling. Station 8 corresponds to a location where TIROS-N imagery frequently reveals the presence of a cold water mass on the southwestern coast of Sakhalin. The area of this cold water mass was marked with a shade pattern in Figure 4-42. It can be seen that it trails southeastward from Cape Krilion, as has also recently been verified by satellite imagery (Science and Technology Agency, 1981).

On the east side of the strait, a sharp thermocline between 10 and 20 meters underlies a low salinity, warm water of the Aniva Bay. A density front (near station 11) separates this water from a relatively high-salinity water on the Hokkaido side. This latter water, forming a very narrow belt against the Hokkaido coast, strongly resembles the surface water on the west side of the strait both in salinity and temperature (about 34 PPT and 16^{o}C).

Figure 4-44 is a summary of a total 1,978 GEK measurements by Japanese oceanographic agencies in the vicinity of the Soya Strait. It is interesting to note that the surface currents approaching the Soya Strait along the west coast of Hokkaido are generally weak. The currents are especially weak in the channel between Rebun Island and the west coast of Hokkaido. There is an indication of an anticyclonic gyre occupying a broad basin west of the strait. A phenomenon of particular importance is that once inside the strait, the current speed

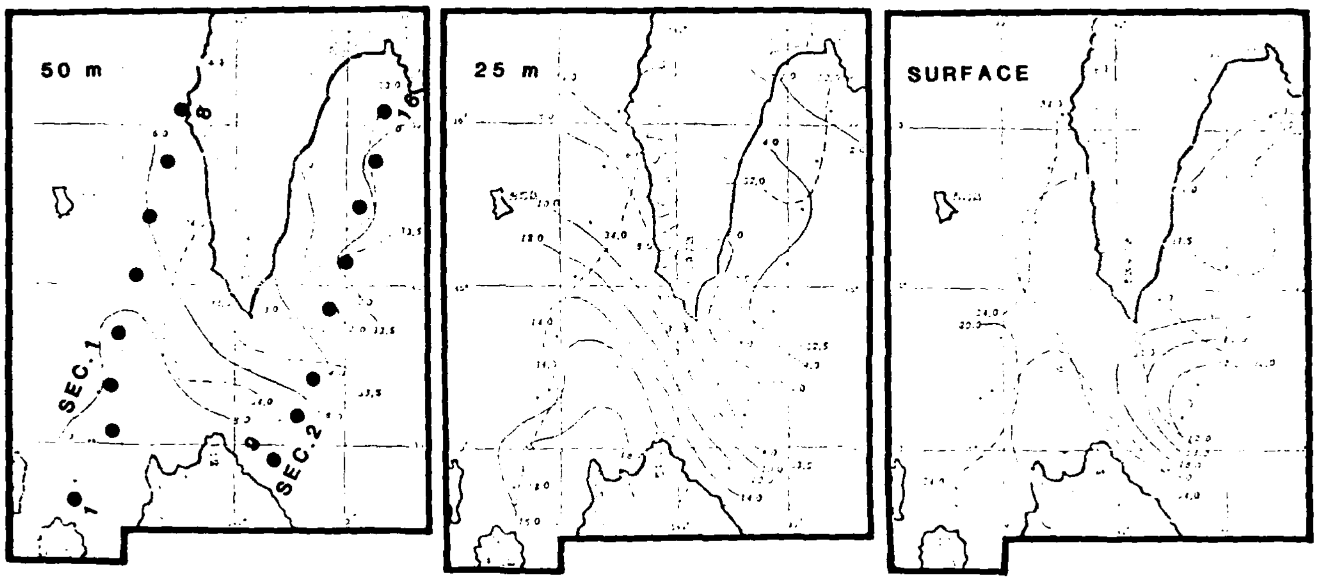


Figure 4-42. Temperature and salinity distributions in the vicinity of Soya Strait in August, 1942. (Hakodate Marine Observatory, 1944)

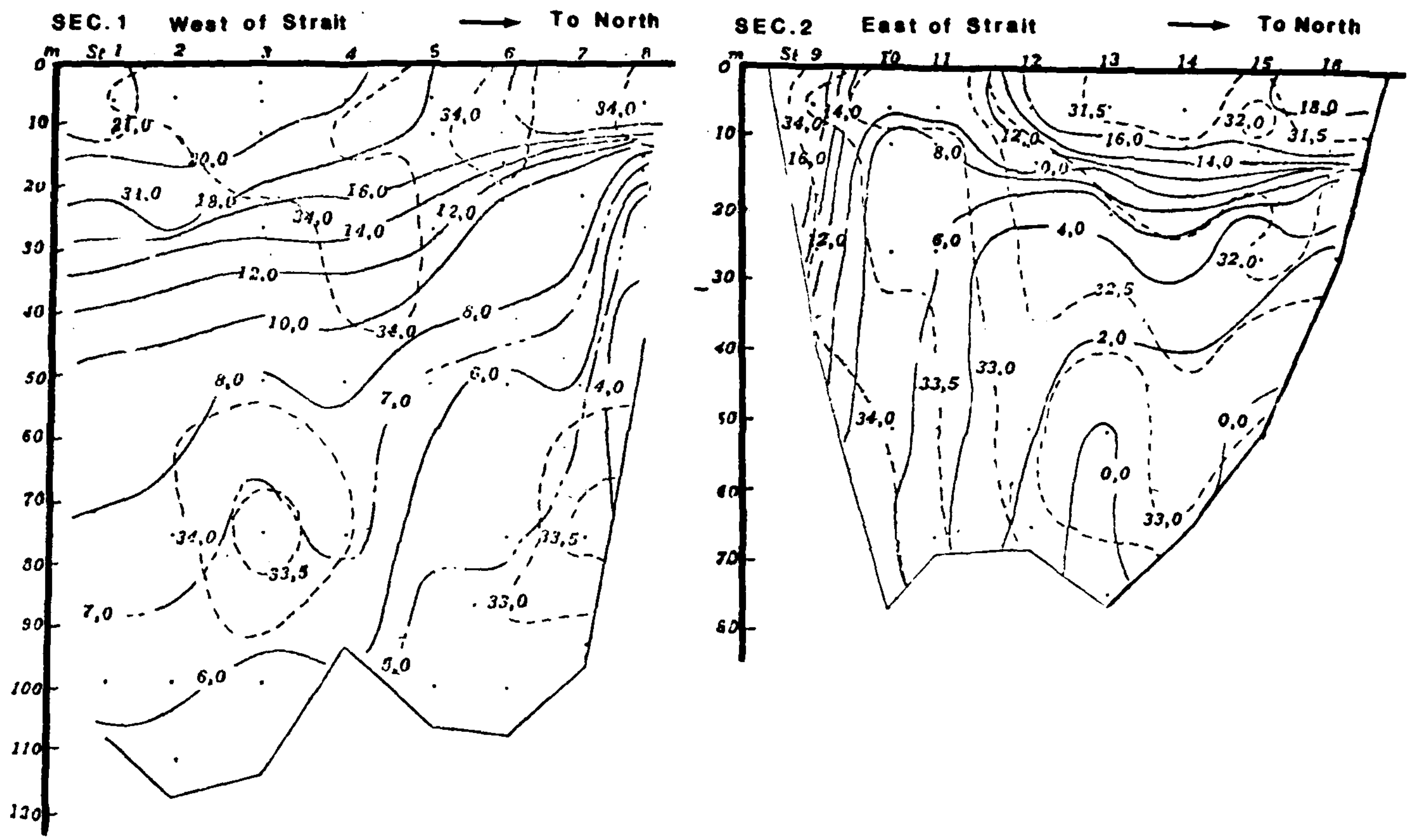


Figure 4-43. Temperature and salinity sections on either side of Soya Strait in August, 1942. (Hakodate Marine Observatory, 1944)

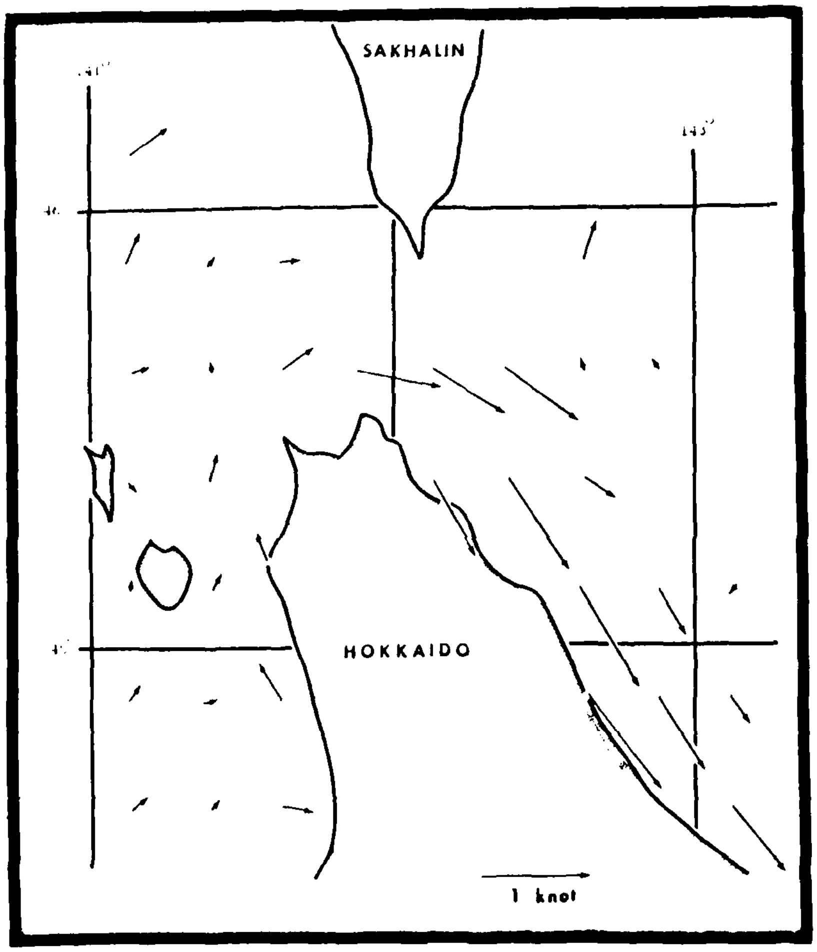
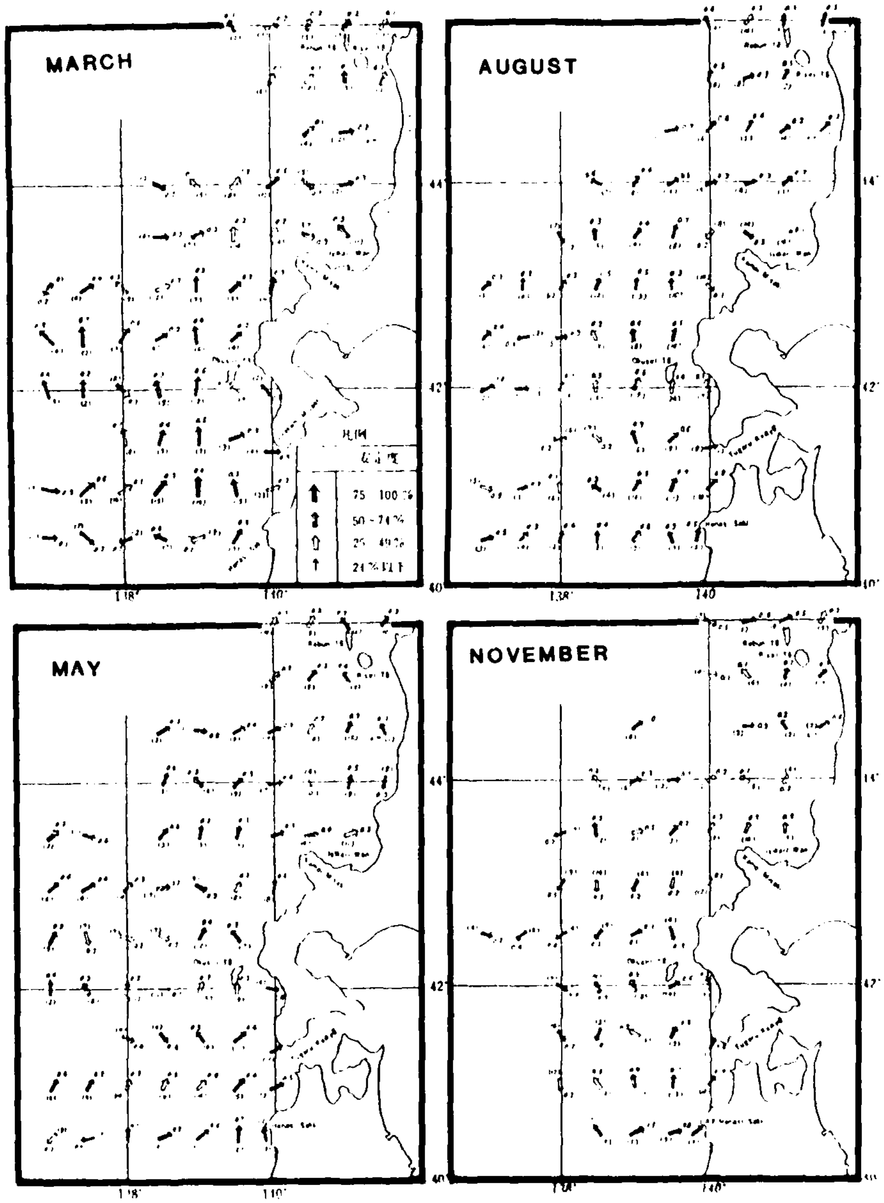


Figure 4-44. Average GEK surface currents in the vicinity of Soya Strait, averaged over each 1/4-degree subsquare.

increases remarkably, and its direction is sharply altered into a southeasterly direction (in contrast to a generally northeasterly direction west of the strait).

It is likely that the inflow dynamics at the Soya Strait may not be a plausible process in which the Tsushima Warm Current arriving from the south along the west coast of Hokkaido may be thought to continue its movement into the strait by simply veering its course eastward while maintaining a coherent stream. It is more likely that the Tsushima Warm Current arrives here with a broad front occupying a large cross-section both on the east and west of Rebun Island. Figure 4-45 shows monthly average GEK records from a total 1,778 measurements between 1958 and 1965 (Nakabayashi and Arai, 1968). The currents moving northward along the west coast of Hokkaido exhibit distinct disarray off Kamoi Misaki where the coastline makes an abrupt change in configuration. There exist signs of eddies and branching at this location. As a result, the current broadens its width, and decreases its speed. By the time the Tsushima Warm Current arrives near Rishiri Island, it still retains a broad width which in August, a peak season, is roughly twice as large as that off the Tsugaru Strait. It is also obvious that the northward velocities occur both on the east and west sides of Rebun Island.

Upon reviewing available literature and data, the present writer proposes the following hypothesis to explain inflow dynamics at the Soya Strait. The Tsushima Warm Current arriving on the west side of the strait would impound the area while attempting to continue its northward advance into the Tartar Strait. It will fill the broad basin west of the strait and engage in active mixing on its western boundary with the cold water mass adjacent to the USSR coast. A super-elevation will result from the continuous impoundment, which will then give rise to a pressure gradient directed to the strait. An inflow will thus take place into the strait, which obviously will entrain a water along the west coast of Sakhalin to fill the northern section of the strait close to Cape Krilion. To replenish this entrainment, there will be an upwelling along the coast of Sakhalin adjacent to Cape Krilion, as already evidenced from satellite imagery as well as by the Yushio Maru cruise. Furthermore, because of the entrainment entering the strait from its north side, the inflow will tend to veer in the southeasterly direction instead of moving directly due east, as also evidenced by the GEK records (Figure 4-44).



( ) denote number of measurement speed in knot.

Figure 4-45. Average monthly GEK surface currents in the approach region to Soya Strait. (Nakabayashi and Arai, 1968)

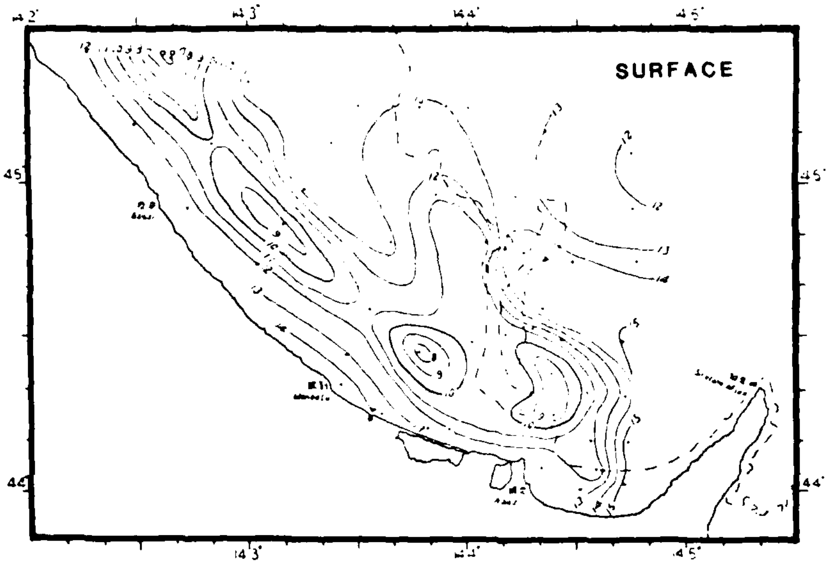
Soya Warm Current

The current which passes through the Soya Strait continues to move southeastward within about 50 km of the Hokkaido coast. This current is called the Soya Warm Current. Its offshore boundary is frequently delineated by a front. In August when the current is most active, its volume transport may rise to 1.3 - 1.4 Sv in the vicinity of Mombetsu (Aota and Kawamura, 1979a). Typical salinities of the Soya Warm Current are 33.6 - 34.0 PPT, somewhat lower than those of the Tsushima Warm Current but distinctly higher than the lower salinity waters of the Sea of Okhotsk.

Figure 4-46 shows temperature distribution on the surface and a 50-m level in July (Japan Hydrographic Office, 1952). A periodic distribution of cold water masses along the outer boundary of the current is a characteristic phenomenon. These cold water masses are not present on a 50-m layer, indicating that they are essentially limited to the surface layer.

Figure 4-47 presents two typical cross-sections off Mombetsu for May and July (Aota et al., 1973). It can be seen that the front, which is dominated more by salinity than temperature gradients, exists from the surface to the bottom, and that the Soya Warm Current may be active to a depth of as much as 150 m during these months. The location of the front can be seen at a distance of about 10 n. miles (about 20 km) from the coast.

The Soya Warm Current exhibits remarkable seasonality. In late March to early April, when the ice leaves the shore, a warm current with its characteristic salinity of 33.6 - 34.0 PPT makes its appearance below the surface off Mombetsu. Its temperature, about 1 - 2°C, is only slightly lower than the 2 - 3°C temperatures recorded at this time within the Tsushima Warm Current region west of Hokkaido (Aota and Kawamura, 1979a). The Soya Warm Current gains its strength rapidly during May to July, and emerges to the surface along the entire northern coast of Hokkaido by August. In the meantime, the current speed almost doubles from around 25 cm/sec in May to around 50 cm/sec in September (Science and Technology Agency, 1981). In late October, the Soya Warm Current begins to shrink shoreward as the low salinity water from the Sea of Okhotsk expands southward, and by late November the Soya Warm Current disappears from the surface.



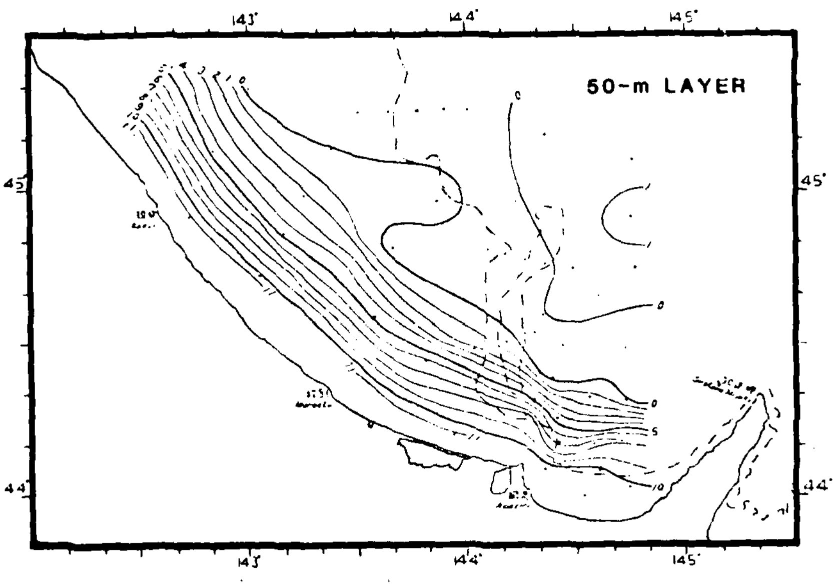


Figure 4-46. Typical temperature distributions in the Soya Warm Current in July, 1951. (JHO, 1952)

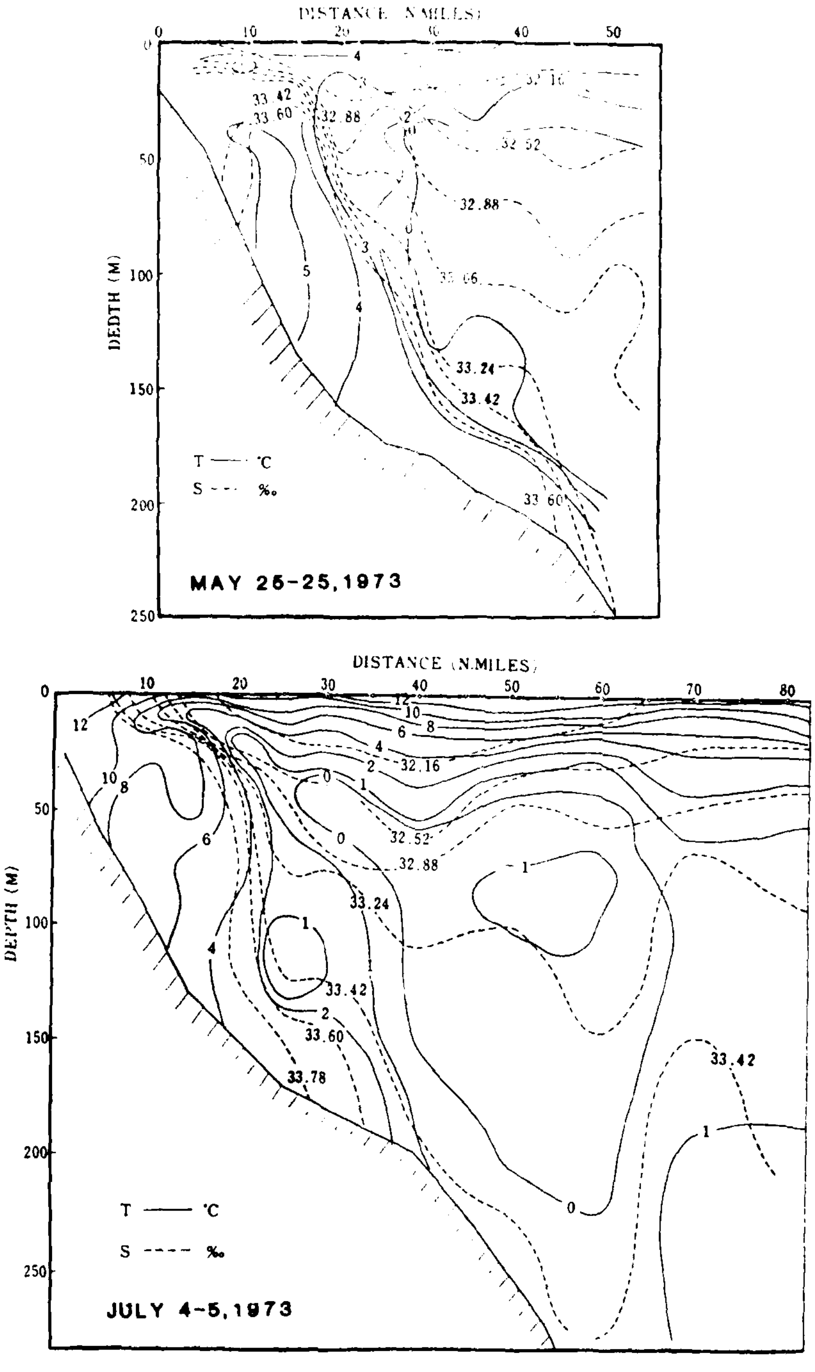


Figure 4-47. Temperature and salinity sections off Mombetsu in May and July, 1973. (Aota, et al., 1973)

The current speed in the Soya Warm Current is much faster on the surface. Long-term averages of GEK records (Figure 4-44) indicates a speed in excess of 1 knot between Cape Soya and Mombetsu. Individual GEK measurements revealed much higher speeds, up to 1.7 knot in spring (April-May), 2.9 knot in summer (August-September) and 1.8 knot in fall (October-November) (Sugiura, 1958).

The tidal currents in the Soya Warm Current region are dominantly diurnal, with semi-diurnal constituents playing a secondary role. Flood currents move to the southeast, ebb currents move to the northeast. Tidal currents exhibit annual highs of about 50 cm/sec (1 knot) in June and July, reducing to about half as strong in September (Science and Technology, 1981).

The Low Temperature Science Institute of the Hokkaido University conducted successful in-situ measurements of current, salinity and temperature under the ice continuously for 4 months from December 1977 to March 1978 (Aota and Kawamura, 1979a). According to this result, even during the ice season, there were occasional bursts of activity by the Soya Warm Current at a depth of about 60 m off Mombetsu. Monthly averages of non-harmonic currents indicated a consistent southeasterly flow at 8 - 16 cm/sec from December to mid-January, less than 6 cm/sec from early to late February (a peak ice season), and 10 - 15 cm/sec toward late March.

Table 4-4 shows temperature and salinity ranges of typical water masses in the vicinity of Soya Warm Current (Iida, 1962). Figure 4-48 shows general location of these water masses. The front consists of a cold intermediate water of the Sea of Okhotsk (Im) with salinities slightly lower than those of the Soya Warm Current. Maeda (1967) proposed that this cold water belt marking the outer boundary of the Soya Warm Current resulted from an upwelling of "dichothermal" water (lying 50 - 100 m below the surface) under the forcing of coast-parallel southeasterly winds which prevail during summer months. Recently, TIROS-N imagery offered the possibility of an alternate interpretation (Science and Technology Agency, 1981). The imagery revealed the presence of a long cold water belt trailing in the southeasterly direction from Cape Krilion, much in the same general location where the cold water belt has been previously recognized by ship cruises. More interestingly, the imagery also revealed, repeatedly, the presence of instability along the cold belt with wave lengths of 50 - 60 km.

TABLE 4-4. Temperature and Salinity Ranges of Typical Water Masses near Soya Strait

TEMPERATURE , °C

		May	August	November
Sw	Soya Warm Current	5.0- 9.0	16.0- 19.0	9.0- 12.0
Im	Intermediate Water	2.0- 5.0	9.0- 15.0	-
Ow	Offshore Warm Water	2.0-	14.0- 16.0	8.0- 10.0
Ls	Low Salinity Water	-	15.0- 16.0	4.0- 6.0

SALINITY, °/oo

		May	August	November
Sw	Soya Warm Current	33.06- 33.96	33.15- 34.05	33.06- 34.15
Im	Intermediate Water	32.16- 32.88	32.34- 32.88	-
Ow	Offshore Warm Water	32.16- 32.52	32.70- 32.88	32.52- 33.06
Ls	Low Salinity Water	-	32.62- 32.16	31.26- 32.16

Note: Data derived and reprocessed from "Iida, H., 1962, On the Water Masses in the Coastal Region of the Southwestern Okhotsk Sea, Jour. Oceano. Soc. Japan, 20th Anniversary Volume, 1962.

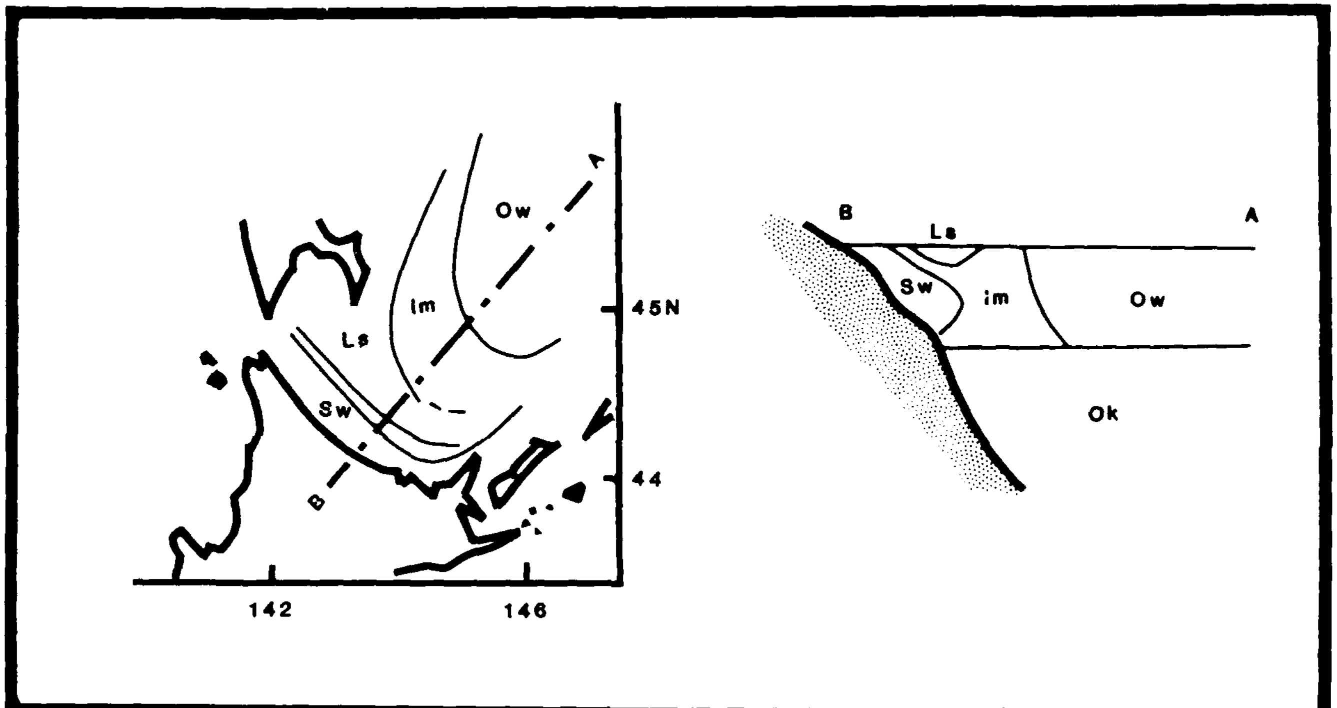


Figure 4-48. Distribution of typical water masses in the region of Soya Warm Current. (Iida, 1962)

Figure 4-49 shows such an instability pattern based on the cruise records of Tankai Maru during October 13-18, 1975. A NOAA-4 thermal IR imagery over this area on October 15, 1975 confirmed the presence of this pattern. It appears that usually the instability forms an average three waves between the Soya Strait and the Shiretoko Peninsula (Science and Technology Agency, 1981). The occurrence of a cold water mass, such as appearing at the trough of the wave pattern in Figure 4-49, has also been reported in the literature (namely, Hakodate Marine Observatory, 1944; Japan Hydrographic Office, 1952). It is quite likely, in view of the different locations along the Soya Warm Current where cold water masses have been reported to occur, that the instability pattern is translatory, moving in the southeast direction. The occurrence of the instability pattern along the cold water belt was not always associated with a favorable southeasterly wind (Science and Technology Agency, 1981). Thus, while a wind-forced upwelling may be one of the possible causes for the formation of a cold water belt at the outer boundary of the Soya Warm Current, another possible cause is the entrainment of a cold water from the west coast of Sakhalin. Because this water is entrained by horizontal eddy mixing with the Soya Warm Current, the boundary is inherently turbulent and would, under certain favorable conditions, evolve a Kelvin-Helmholz instability.

This is a good example in which a satellite surveillance capability can successfully complement the sparsely distributed surface cruise data. A three-dimensional hydrodynamics associated with such an instability mechanism in the Soya Warm Current region will be an extremely interesting subject of study in the future, particularly by the numerical modelers.

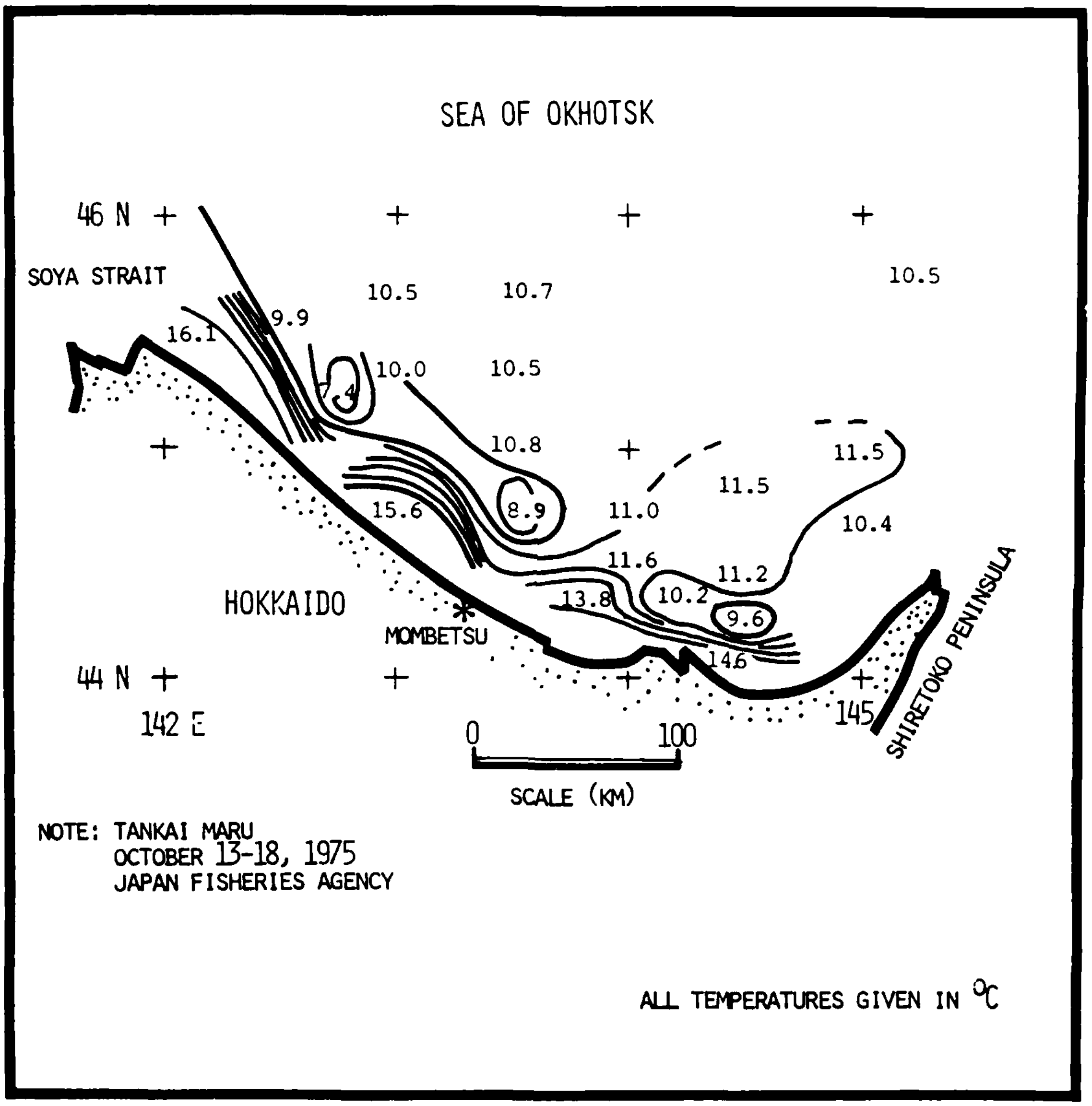


Figure 4-49. Instability pattern at the density front of Soya Warm Current.

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5. ANNOTATED BIBLIOGRAPHY

5.1 Tsushima Strait

Tsujita, T., 1954a. Some theoretical considerations on the ecosystem in the Warm Tsushima Current (I) (Japanese with English abstract). Journ. Oceanographical Soc. of Japan, 10(3), pp. 133-157.

With primary interest in the relationship between ecological productivity and physical oceanic system, the another takes Lagrangian approach to focus on mesoscale processes such as vortices, upwelling, and offshore entrainment of coastal water along the coastal front in the region of the Tsushima Warm Current. Figure 1 and Table 1 show the vortices which were either directly observed or theoretically deduced from data. Figure 2 and Table 2 summarize the coastal fronts which mainly appear during fall to spring. Table 3 summarizes the position and strength of thermocline.

Tsujita, T., 1954b. On the observed oceanographic structure of the Tsushima fishing grounds in winter and ecological relationship between the structure and fishing conditions. (Japanese with English abstract) Journ. Oceanographical Soc. of Japan, 10(3), pp. 158-170.

From field observations in the winter of 1949 and in the spring of 1953, the author was able to recognize topographically controlled vortices, current rips and stratifications adjacent to the Tsushima Islands. Distribution of these features is found to be essentially comparable to situations which would result from impingement of a stratified current against an ellipsoidal object at oblique angles.

Tsujita, T., 1954c. On the observed oceanographic structure and the development of stratified water currents in the Straits of Tsushima and the Sea of Goto-Amakusa in the Western Japan (Japanese with English abstract). Bull. Seikai Regional Fisheries Research Lab., No. 1, pp. 1-32.

The author presents interesting schematics of eddies and frontal structures in the vicinity of the Tsushima Islands based on data interpretation and literature survey.

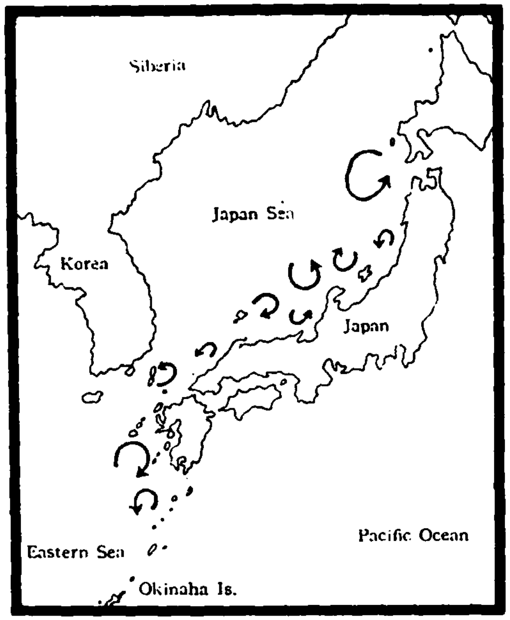


Fig. 1. Schematic chart representing vortex movements in the Tsushima Current System

Figure 1. (Tsujita, 1954a).

Locality	Direction of voltex movement	Date of observation	Authority
1. Off the west of the Straits of Tsushima	Anticlockwise	May-June, 1932	Suda, K., Uda, M., 1934
2. Off the north-west of Sakata, Honshu	Anticlockwise	August, 1948	Sato, K., 1950
3. Near the position 38°~38.5° N. 137°~138°E, noth-west of Sado I.	Clockwise	August, 1948	Sato, K., 1950
4. Northern sea area of the waters off Noto Peninsula	Clockwise	August, 1946	Nakamiya, M., 1947
5. Northern sea area of the waters off Noto Peninsula	Clockwise	August, 1948	Sato, K., 1950
6. Sea area north-west of Noto Peninsula	Anticlockwise	May-June, 1932	Uda, M., 1934
7. About 60 miles north of Wakasa Bay	Anticlockwise	May-June, 1947	Yoshida, S., 1952
8. Off the north of Wakasa Bay	Anticlockwise	August, 1948	Sato, K., 1950
9. About 90 miles north-north-east of Oki I.	Clockwise	May-June, 1947	Yoshida, S., 1952
10. In the Bay of Wakasa	Anticlockwise	May-June, 1932	Uda, M., 1931, Uda, M., 1934
11. Off Hamada to the north-west	Anticlockwise	August, 1948	Sato, K., 1950
12. Northern sea area of the waters north of the Tsushima Islands			Suda, K., 1938
13. Off the east of the Tsushima Is. in the Straits of Tsushima	Anticlockwise	December 1949 April, 1953	Tsujita, T., 1950, 1952 and 1954
14. In the Sea of Gotō-Amakusa	Clockwise	All round the year in the mid-depth	Uda, M., et al
15. 50 miles south-west of Yaku I.; the centre of the cyclonic eddy 30° N, 123° E	Anticlockwise	April, 1947	Kurashina, S. 1952

Tab. 1. Vortex movements in the warm current Tsushima along the Islands of Japan shown in Fig. 1

Table 1. (Tsujita, 1954a).

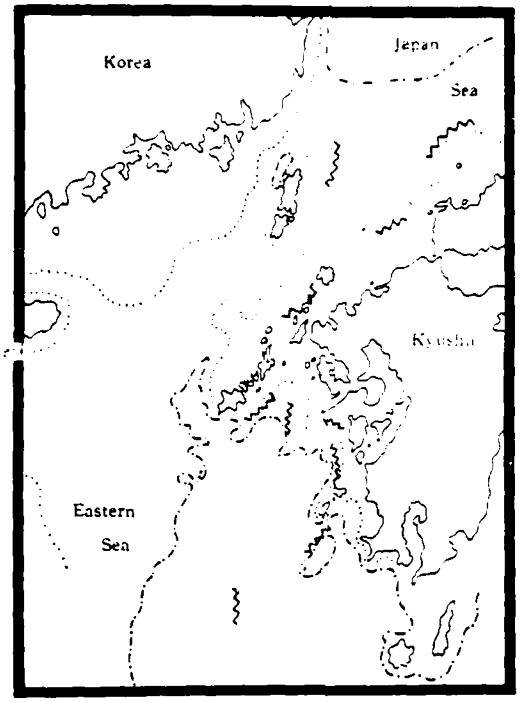


Figure 2.
(Tsujita, 1954a).

Coastal front

Chart of the waters west of Japan showing the horizont. boundaries described in the text and Tab. 2.

Tab. 2. Position and strength of coastal fronts denoted by $\left(\frac{\Delta T}{\Delta S}\right)_{max}$ off the coast of western Japan during the years 1952, 1953.

Month / Sea part	Oct.	Nov.	Dec.	Jan.	Feb.	March		Apr.	May
Waters north of the Tsushima Islands	/	/	/	2nd d. 0.2	/	/	/	/	.
Iki Channel	1st decade 0.2	1st d. 0.1	2nd d 0.1	2nd d. 0.5	1st d. 0.2	/	3rd d. 0.06	1st d. 0.1	2nd d 0.06
Central part of the Sea of Goto-Amakusa	3rd d. 0.3	2nd d. 0.2	2nd d. 0.2	2nd d. 0.2	1st d. 0.1	1st d. 0.1	3rd d. 0.2	3rd d. 0.1	2nd d. 0.1
Off southern Amakusa in the Sea of Goto-Amakusa	2nd d. 0.3	3rd d. 0.1	2nd d. 0.5	2nd d 0.5	/	1st d. 0.1	3rd d. 0.0	/	2nd d 0.2
Between Nomazaki and the Koshiki Is.	3rd d. 0.5	3rd d. 0.2	2nd d 0.2	/	1st d. 0.3	/	3rd d. 0.04	1st d 0.1	.
Between Nomazaki and the Uzi Is.	3rd d. 0.04	/	2nd d. 0.4	/	/	1st d. 0.1	3rd d. 0.02	.	2nd d 0.2
Waters south-west of the Uzi Is.	3rd d. 0 04	/	2nd d. 0.04	/	/	1st d. 0.3	/		2nd d 0.4

Table 2. (Tsujita, 1954a).

Tab 3 Position and strength of thermoclines

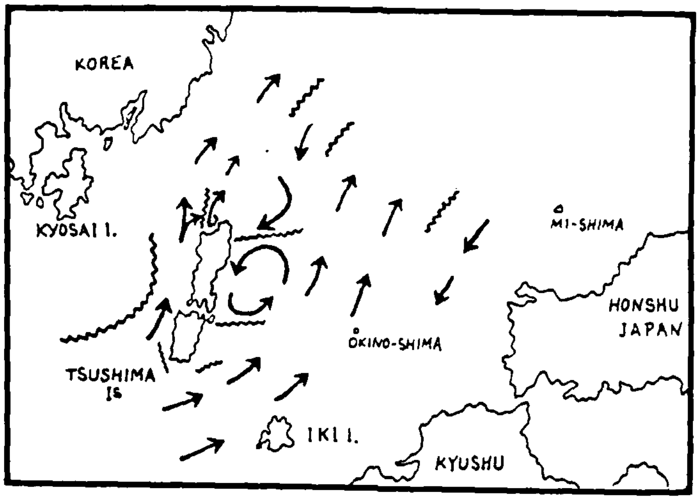
	June	July
Straits of Tsushima	(The 1st decade) A weak discontinuity layer slightly recognizable in the waters around Oki Island. Temperature gradient $\Delta T/\Delta S$ 1 °C/10-20 m. stratum.	(The 2nd decade) Appearing partly in the core of the warm Tsushima Current. $\Delta T/\Delta S$ 5 °C/25-50 m. stratum. Northern area of the straits, $\Delta T/\Delta S$ 3 °C/10-30 m. stratum Southern area of the straits.
Near the Iki Channel	/	/
Central part of the Sea of Goto	(The 2nd decade) The discontinuity layer not developed yet, and stratification seen distinctively.	(The 2nd decade) Development of stratification notable; whereas value of the $\Delta T/\Delta S$ of each layer became large, and the discontinuity layer not developing.
Off the Amakusa Is.	(The 1st decade) The discontinuity layer not appeared yet. A coastal front remained near the coast of Amakusa Is.	/
Sea area from Noma Zaki to the Koshiki Is.	(The 2nd decade) Comparatively formal stratification can be seen, but its upper layer unstable to some extent.	(The 1st decade) $\Delta T/\Delta S$ of the upper layer large, but no discontinuity layer seen.
Sea area from Noma Zaki to the Uzi Is.	/	(The 3rd decade) $\Delta T/\Delta S$ of each layer large, but no discontinuity layer can be seen.
Westward off the Uzi Is.	/	(The 3rd decade) Although the upper layer slightly unstable, there could be seen strong stratification in the mid-depths. The discontinuity layer not appeared yet.

Table 3. (Tsujita, 1954a).

Tab. 3. Position and strength of thermoclines

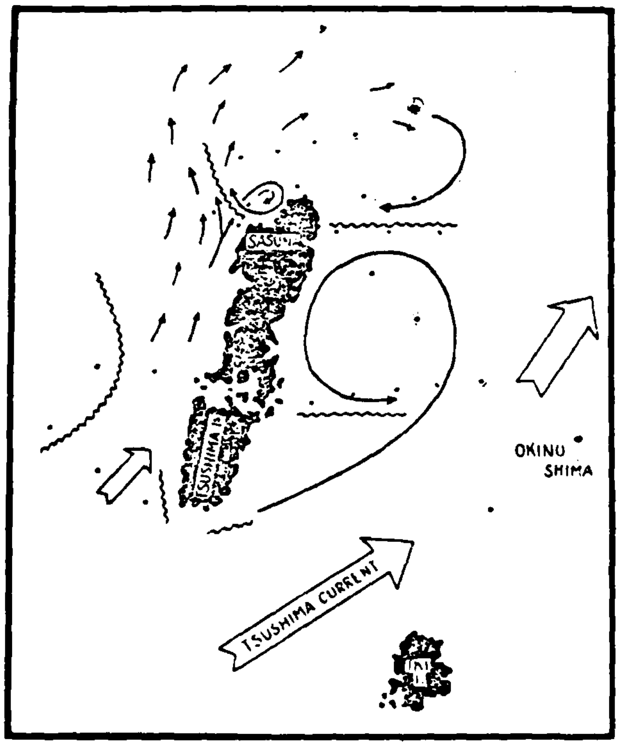
	August	September	October
Straits of Tsushima	(The 2nd decade) A discontinuity layer present. $\Delta T/\Delta S$ 8 °C/20-50 m. stratum.	/	(The 1st decade) A remarkable discontinuity layer seen below the mid-depths. $\Delta T/\Delta S$ 5 °C 50-75 m. stratum.
Near the Iki Channel	/	/	(Ukuzima-Tsushima-Futagami Is.) The upper layer unstable and the temperature gradients in the bottom layer large. The discontinuity layer not yet recognizable.
Central part of the Sea of Goto	(The 1st decade) A discontinuity layer present. $\Delta T/\Delta S$ 3 °C/5-10 m. stratum. (The 2nd decade) A discontinuity layer present. $\Delta T/\Delta S$ 6 °C/10-25 m. stratum.	(The 2nd decade) The developed discontinuity layer present. $\Delta T/\Delta S$ 4 °C/50-75 m. stratum.	(The 2nd decade) Though the upper layer unstable, yet a coastal front begun to appear. $\Delta T/\Delta S$ 3 °C/50-75 m. stratum.
Off the Amakusa Is.	(The 2nd decade) A discontinuity layer present. $\Delta T/\Delta S$ 4°C/15-25 m. stratum.	/	(The 2nd decade) The upper layer unstable and development of the coastal front could be seen off Ushibuka of the Amakusa Is. $\Delta T/\Delta S$ 3 °C 60-90 m. stratum.
Sea area from Noma Zaki to the Koshiki Is.	(The 3rd decade) A discontinuity layer present. $\Delta T/\Delta S$ 7 °C/50-75 m. stratum.	(The 3rd decade) A weak discontinuity layer present. $\Delta T/\Delta S$ 3 °C/30-60 m. stratum.	(The 3rd decade) The upper layer unstable and a coastal front begun to appear. A discontinuity layer present in the mid-depths. $\Delta T/\Delta S$ 4 °C 50-75 m. stratum.
Sea area from Noma Zaki to the Uzi Is.	/	(The 1st decade) The upper layer unstable and there could be seen stable stratification below the mid-depths. Discontinuity layer absent.	(The 3rd decade) Stability large in the deeper layer than the mid-depths. The upper layer above 75 m. depth unstable.
Westward off the Uzi Is.	/	/	(The 3rd decade) Stability large in the deeper layer than the mid-depths and the upper layer above 75 m. depth unstable.

Table 3 (Cont'd). (Tsujita, 1954).



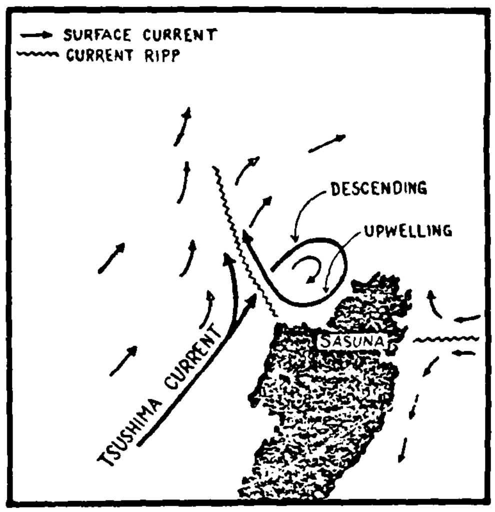
Schematic chart showing observed physical structure and circulation pattern for the waters around the Tsushima Islands in winter

Figure 1. (Tsujita, 1954b).



Schematic chart showing oceanographic structure of waters surrounding the Tsushima Islands.

Figure 1. (Tsujita, 1954c).



Circulation pattern showing schematically the stratified waters in steady state off Sasuna in the upper principal island of the Tsushima Is.

Figure 2. (Tsujita, 1954c).

Yi, Sok-U, 1966. Seasonal and secular variations of the water volume transport across the Korea Strait. Journal of Oceanological Society of Korea, 1(1-2), pp. 7-13.

Voloume transport through both West and East Channels of the Tsushima Strait is investigated using geostrophic calculations on the basis of data between 1932 through 1941 and between 1960 through 1965. The calculated seasonal transport was found to fluctuate between annual maximum of about 2.21 Sv in summer-fall and annual minimum of about 0.33 Sv in winter-spring. Annual net northward transport varied between a record high of 1.3 Sv in 1935 and a record low of 0.85 Sv in 1939. Annual transports appeared to exhibit a four-year periodicity between 1930 and 1940. See Figures 1 and 2.

Yi, S.U., 1967. On the variations of monthly mean sea levels along the coast of Korea (Korean with English abstract). Journ. of Oceanological Soc. of Korea, 2(1), pp. 24-33.

Analysis was performed on the monthly mean sea level data between around 1962 and 1966 at Ullungdo, Mukho, Ulsan, Pusan (or Busan). Chinhae, Yosu, Cheju (or Jeju), Mokpo and Inchon. The variations in monthly mean sea level were found to be related mainly to steric and atmospheric effects. The steric effect was most pronounced on the east coast facing the Sea of Japan and the south coast facing the Tsushima Strait, particularly at Pusan. Additional causes were river runoff on the west coast, and possibly the fluctuation of oceanic currents along the east and south coasts. The monthly mean sea levels were high in summer-fall and low in winter-spring, with a range of 20 - 50 cm.

Nan-niti, T. and A. Fujiki, 1967. Secular variation of hydrographic conditions in the East Tsushima Strait (Japanese with English abstract). Journ. Oceanographical Soc. of Japan, 23(4), pp. 201-212.

A time-series data consisting of 40-year (1913-1952) monthly serial observations across the East Channel of the Tsushima Strait by the Fukushima Fisheries Experiment Station is analyzed to ascertain secular variation. Monthly mean temperature and salinity sections (Figure 1) indicate three typical types: a well-mixed type for December-March, a stratified type for June-October, and a transition type for other months. The current axis appears to be located near

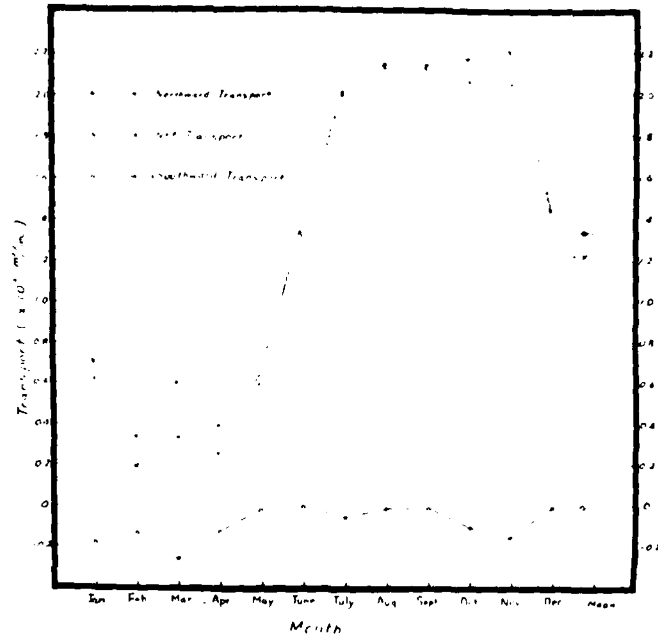


Figure 1. Monthly volume transport (Yi, 1966).

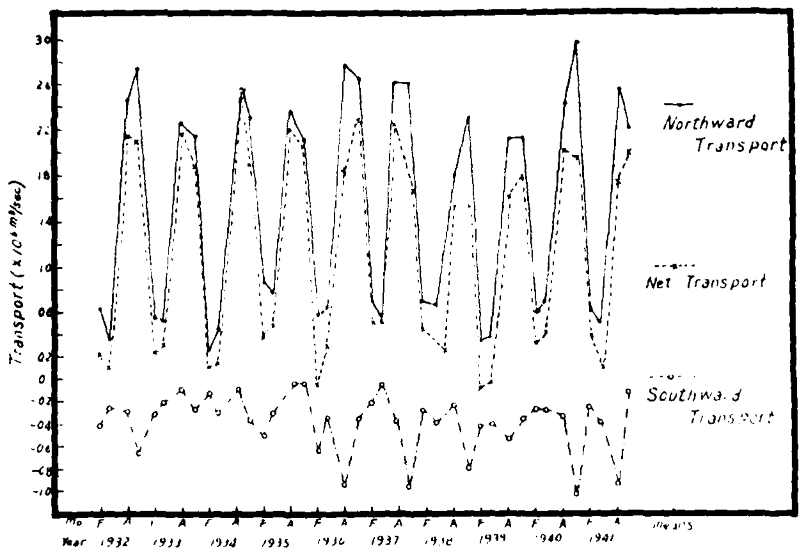


Figure 2. Annual volume transport (Yi, 1966).

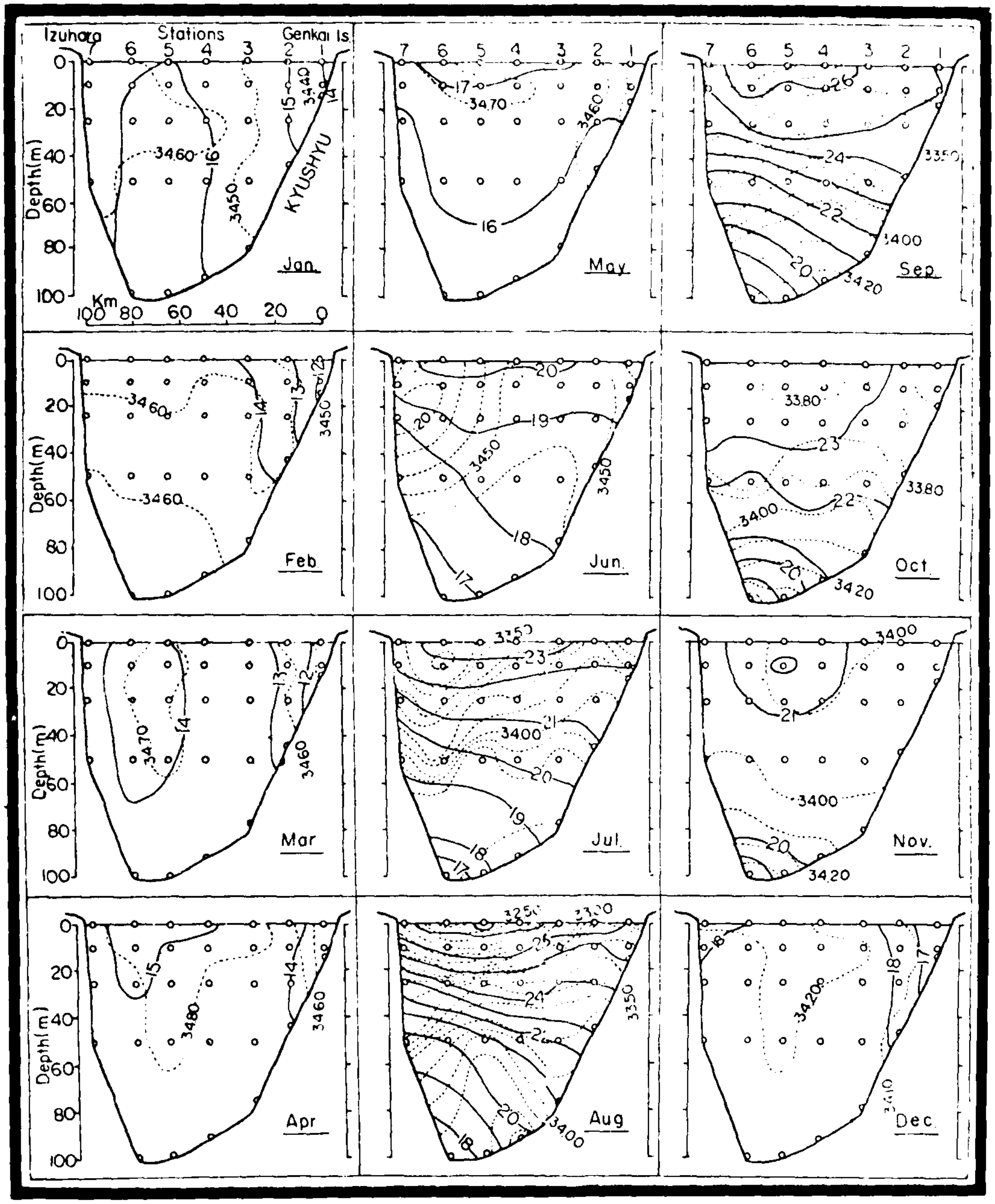
St. 6, closer to the Tsushima Island. Salinity drops abruptly after June to a minimum in August, suggesting entrainment of water from the Yellow Sea. A power spectrum analysis (Figure 2) failed to reveal any significant periodicity. A correlogram analysis (Figure 3) of SST along the current axis revealed a periodicity of about 2 years. Annual mean temperature variations (Figure 4) appeared to indicate periodicities of about 9 years along the current axis, and 7 and 9 years at St. 1 and 4.

Gong, Y. and C.K. Park, 1969. On the oceanographical character of the low temperature region in the Eastern Sea of Korea. (Korean with English Abstract) Bull. Fisheries Research and Development Agency, No. 4, pp. 69-91.

Characteristics of the cold water region along the southeast coast of Korea north of the Tsushima Strait are investigated using data of the Fisheries Experiment Station of Korea 1925-34, the Central Fisheries Experiment Station 1957-60, Fisheries Research and Development Agency 1961-67, and the CSK cruises 1965-69. The cold water region is typically situated west of the East Korean Warm Current and usually extends to the vicinity of Ullungdo. The water mass in this region is considered to be formed by the North Korean Cold Current or as a result of mixing between the N.K.C.C. water and the mid-layer of the Tsushima Warm Current. The cold water mass which is well developed during June through September is distinctly stratified with the thermocline as much as 150-meter deep. The region is bounded by a stationary cyclonic gyre and characterized by low temperature (about $5^{o}C$), low salinity (33.80 - $34.10^{o}/oo$) and high D.O. content (6.2 cc/L).

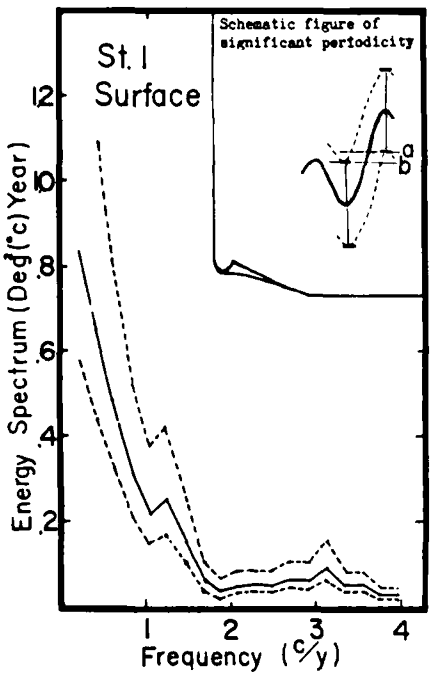
Gong, Y., 1970. A study of the South Korean coastal front. A paper presented in the 2nd CSK Symposium, 28 Sept. - 1 Oct., 1970, Tokyo, CSK News Letter Issue No. 31, December 1970. Also, a Korean paper with English abstract in Journ. Oceanological Soc. of Korea, 6(1), 1971, pp. 21-36.

The South Korean coastal front, so named by Uda (1958), is formed where the Tsushima Warm Current meets the South Korean coastal water and usually extends between the vicinity of Jeju (or Cheju) Island and Tsushima Islands. Oceanographic cruise data during the 26 cruises in 1967-69 within 150 miles of the southern coast of Korea



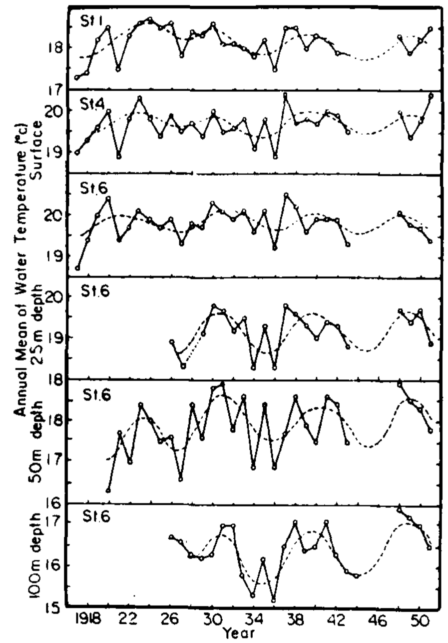
Monthly vertical sections of temperature in degrees centigrade (T°C thin line) salinity in perts per mille (S ‰ dotted line) in the Tsushima Strait.

Figure 1. (Nan-niti and Fujiki, 1968).



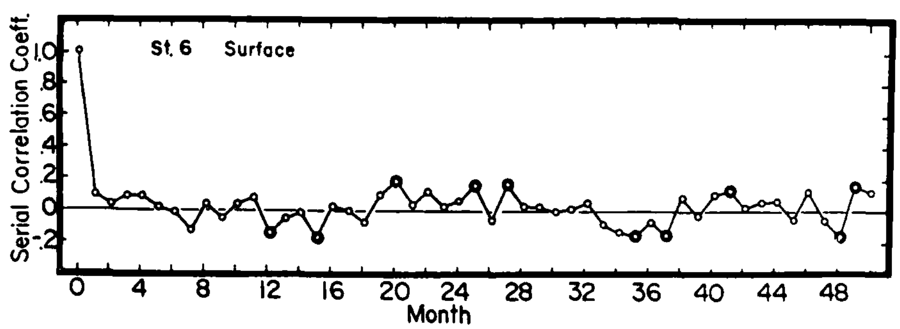
Energy spectrum of surface water temperature at St. 1.

Figure 2. (Nan-nita and Fujiki, 1967).



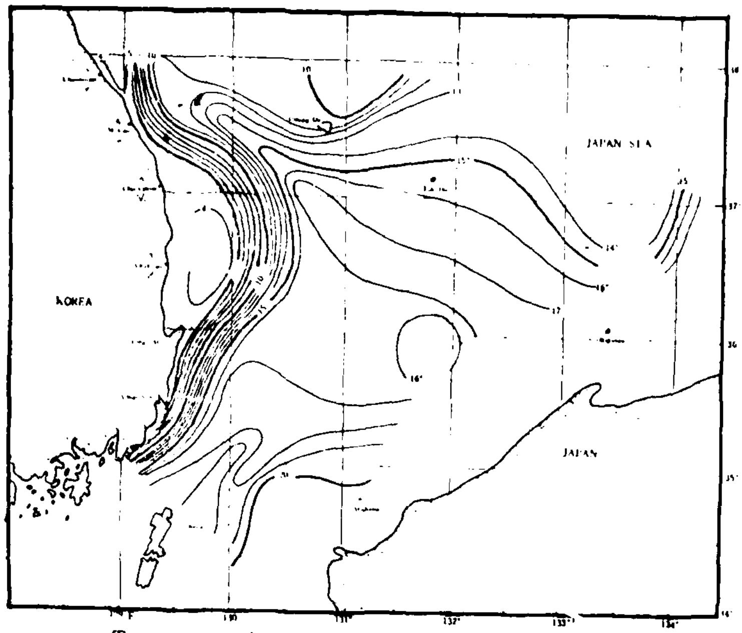
Variations of annual mean of water temperature at Sts. 1, 4 and 6.

Figure 4. (Nan-niti and Fujiki, 1968).



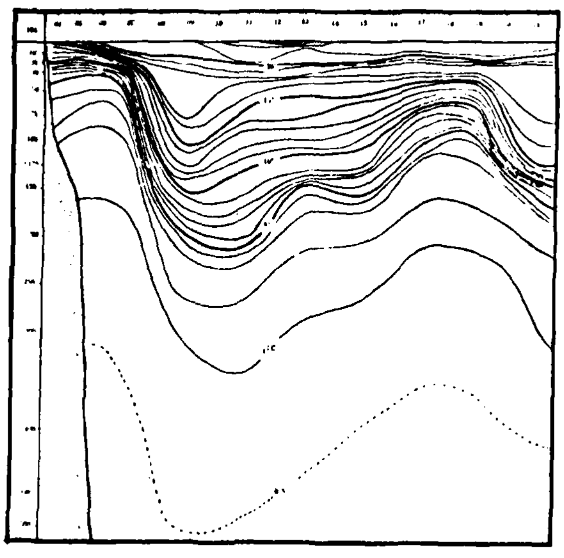
Correlogram of surface water temperature at St. 6. Double circle shows the significant value at the 5% level.

Figure 3. (Nan-niti and Fujiki, 1968).



Temperature (℃) at 50 meter--layer on 12- 27 July 1966.

Figure 1. Gong & Park, 1969.



Temperature (℃)

Figure 2. Temperature

Temperature section along line 104 (parallel to Lat. 37N) in July 1966. (Gong & Park, 1969.)

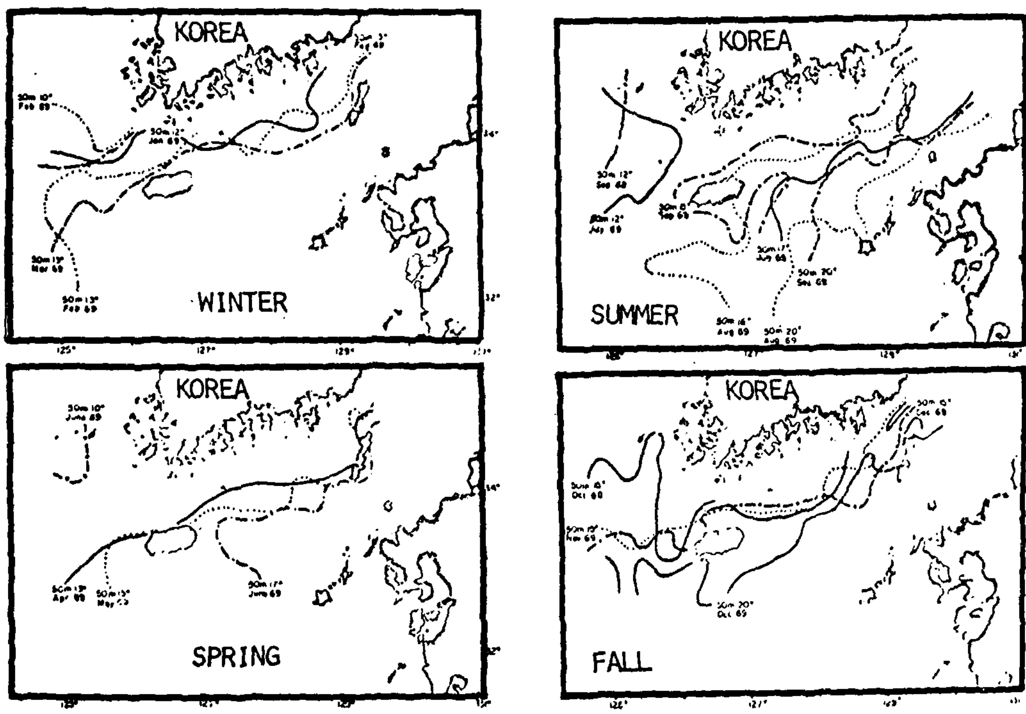


Figure 1. Seasonal fluctuation of the South Korean coastal front. (Gong, 1970).

reveal the presence of this front, somewhat more distinct and stable in fall and winter, across which there exist sharp gradients both in temperature and salinity. The paper gives seasonal fluctuation of the position of the front.

Yi, Sok-U, 1970. Variations of oceanic condition and mean sea level in the Korea Strait. In "The Kuroshio," ed. by J.C. Marr, East and West Center, Hawaii, pp. 125-140.

Using serial oceanographic data obtained by Korea Fisheries Research and Development Agency, and tidal data at five stations facing the Tsushima Strait between 1962 and 1967, the author investigates relationship between steric sea level vis-a-vis recorded sea level and their effects on the current in the West Channel.

> "The tide in the strait was discussed by Ogura (1933). The semidiurnal tidal wave rotates counterclockwise around an amphidromic point a little west of the midpoint of the northeast end of the strait. The spring range of tide is about 220 cm along the coasts of the Goto Islands, about 330 cm on the coast of Korea near the southwest end to the strait. It decreases gradually to the northeast along the shores of the strait to about 20 cm and 10 cm at the coasts of Honshu and Korea at the northeast end."

> "Along the Tsushima Islands the flood current flows to the south, the ebb current to the north. Their directions reverse at about the time of high and low waters. In the eastern part of the south coast of Korea, the flood current goes to the southwest, the ebb current to the northeast off the coast, and reverse their directions at about the time of high and low waters. In the western half of the same coast, the current generally sets to the east and west in the offing, the west-going current running from 2-3 hours after low water to 2-3 hours after high water, with maximum velocity of 2 to 3 knots at narrows."

> "Nishida's (1927) 24-hour current observations in the western channel show that the components of semidiurnal and diurnal tidal current are 0.7-1.3 knots and 0.4-0.7 knot in the upper layer, respectively, and the strength of tidal currents is almost the same from the surface to the bottom."

A good agreement was found between the monthly mean sea levels reduced to normal atmospheric pressure and computed steric sea levels at Busan (or Pusan), Jeju (or Cheju) and Izuhara (on Tsushima Island). See Figure 1. A good correlation is also found between sea level differences (Izuhara-Pusan) and computed average current velocities in the West Channel.

Burns, D.A., 1975. Tidal frequency oscillations on the Tsushima Current. NAVOCEANO Technical Note No. 6110-4-75. 31 p.

Six Geodyne A-101-1 current meters, taut moored in two three-meter arrays in the West and East Channels of the Tsushima Strait in October 1972, yielded approximately 550 hours of continuous records each. The current meters were positioned in the surface, middle and bottom layers. Another nearsurface meter, a Q-15 model, yielded approximately 120 hours of record at one array. In both channels and at all depths, the major constituents were found to be Mz, Sz, Kl and Ol. At least 75 percent of all the N-S flow, and 69 percent of all the E-W flow could be attributed to tidal oscillations. Major axes of the tidal ellipses were essentially in agreement with the orientation of the channels.

Huh, O.K., 1976. Detection of oceanic thermal fronts off Korea with the Defense Meteorological Satellites. Remote Sensing of Environment, 5, pp. 191-213.

Using thermal infrared imagery from the Air Force Defense Meteorological Satellite Program (DMSP), the behavior of a coastal front off the Korean coast facing the Tsushima Strait was investigated. The imagery reveals the South Korean coastal front extending a considerable distance into the West Channel and a complex structure along the front involving such features as local upwelling associated with Meso-scale eddies and diffusive plumes.

Ogawa, Y., T. Nakahara, and R. Tanaka, 1977. Hydrographic nature of coastal fishing grounds in the southwestern Japan Sea. Bull. Seikai Regional Fisheries Research Lab., No. 50, pp. 73-126.

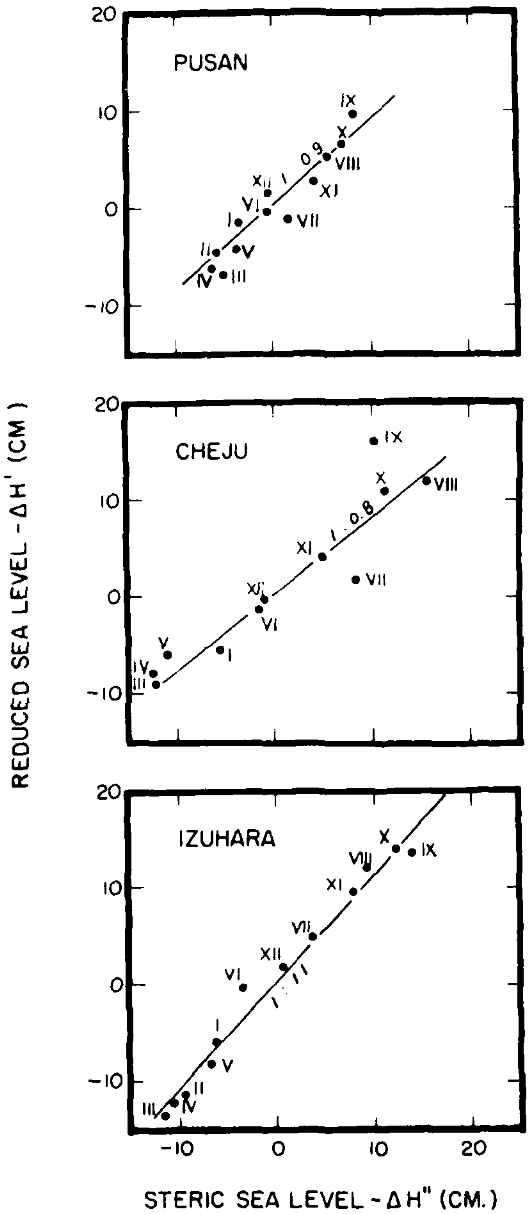
Analysis of oceanographic data obtained from the serial surveys during 1973-75 reveals that the coastal water in the southwestern Sea of Japan is dominantly influenced by the offshore low-salinity water known as "Upper water of the Tsushima current" originating in the East China Sea, rather than by the influx fresh water from local rivers. Distinct low-salinity water masses which form in the coastal region results from the initial supply of the low-salinity offshore water in summer and subsequent processes of convective overturn commencing in early fall. Thus, the occurrence of low-salinity coastal waters in the southwestern Sea of Japan is restricted to the fall season.

Lee, K.B., 1978. Study of the coastal water near Ulsan. Journ. of Oceanological Soc. of Korea, 13(2), pp. 5-10.

A cold water mass which customarily appears off Ulsan, Korea, on the West Channel of the Tsushima Strait during summer months is related to an anticlockwise gyre occurring between the axis of the incoming Tsushima Warm Current and the Korean coast. The cold water is typically situated near the southern end of this gyre where the southerly current turns east (offshore), indicating that the cold water upwelling is induced at this location. See Figures 1 and 2.

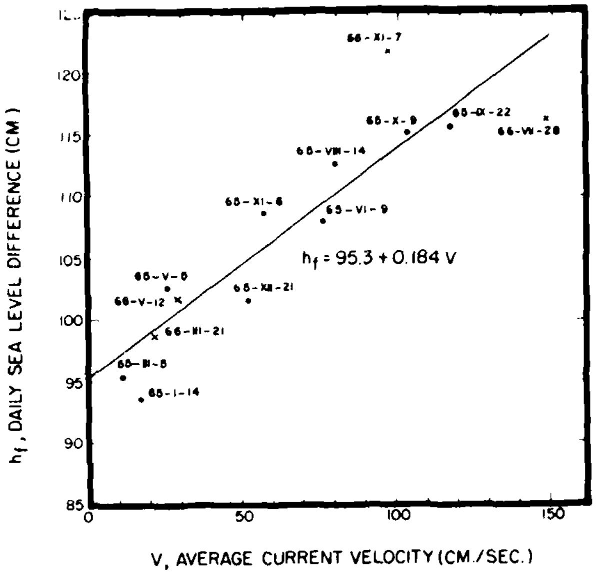
Ogawa, Y., T. Miita, A. Ichihara, Y. Hasegawa and N. Inoue, 1979. Fluctuations of the Tsushima Current measured with the current drogue. Bull. Seikai Regional Fisheries Research Lab., No. 51, pp. 13-43.

A total of 27 runs of current drogue in the East Channel of the Tsushima Strait, performed between 1973 and 1976, were analyzed. Drogues at 5 m from the surface exhibited average speeds of between 0.3 and 0.9 knot, with slightly longer values offshore than nearshore. Whereas the surface current in the offshore region revealed fluctuations of predominantly tidal cycles, the nearshore surface current contained fluctuations of shorter periods averaging a few hours. A meso-scale fluctuation with a period of a few days was detected in one experiment, which appeared to be associated with



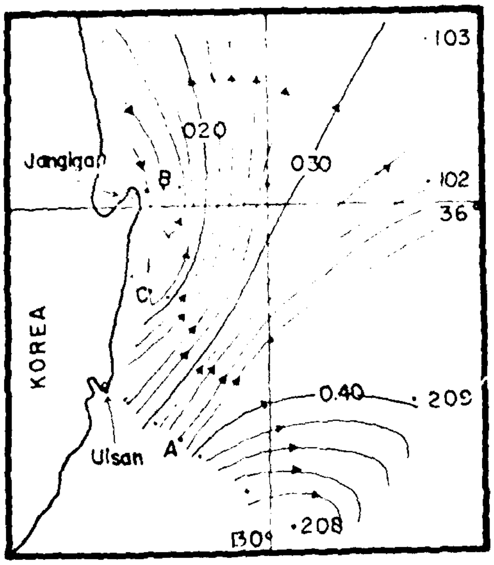
Relations between monthly mean sea level and steric sea level at Pusan, Cheju, and Izuhara.

Figure 1. (Yi, 1970).



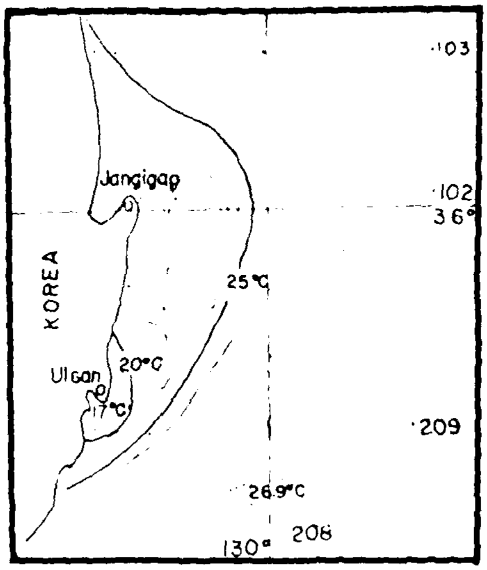
Relation between Izuhara-Pusan daily mean sea-level differences and average current velocities computed by Margules' equation in the western channel.

Figure 2. (Yi, 1970).



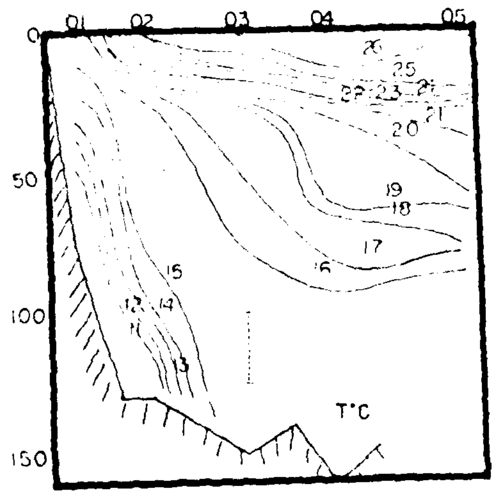
The surface dynamic topographies over 100db surface in August, 1969.

Figure 1. (Lee, 1978)



The distributions of surface temperature in August, 1969.

Figure 1. (Lee, 1978).



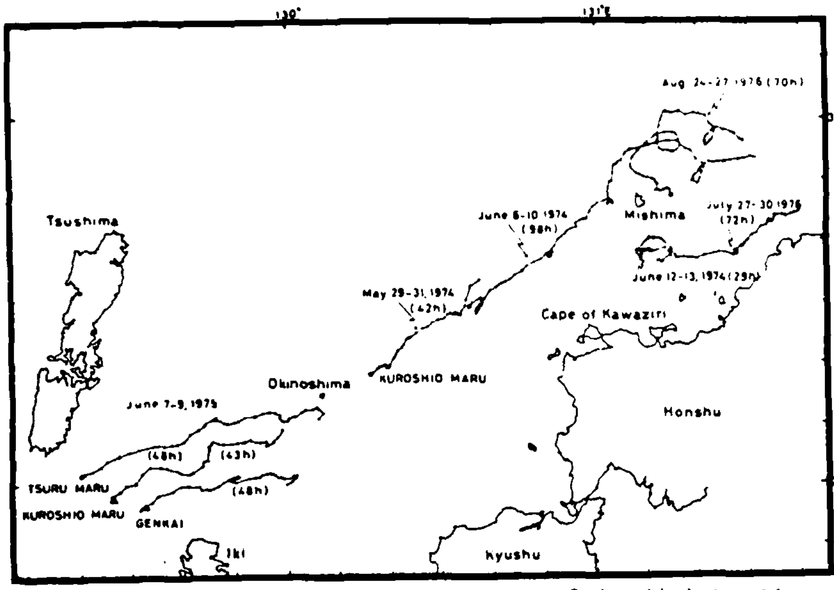
The vertical distribution of temperature along observation line 208 in August, 1969.

Figure 1. (Lee, 1978).

atmospheric disturbances. Deep drogues exhibited movements widely inconsistent with those of the simultaneously tracked surface drogues. Trochoidal-shaped trajectories associated with diurnal tidal cycle, and possibly by the inertia current, were observed.

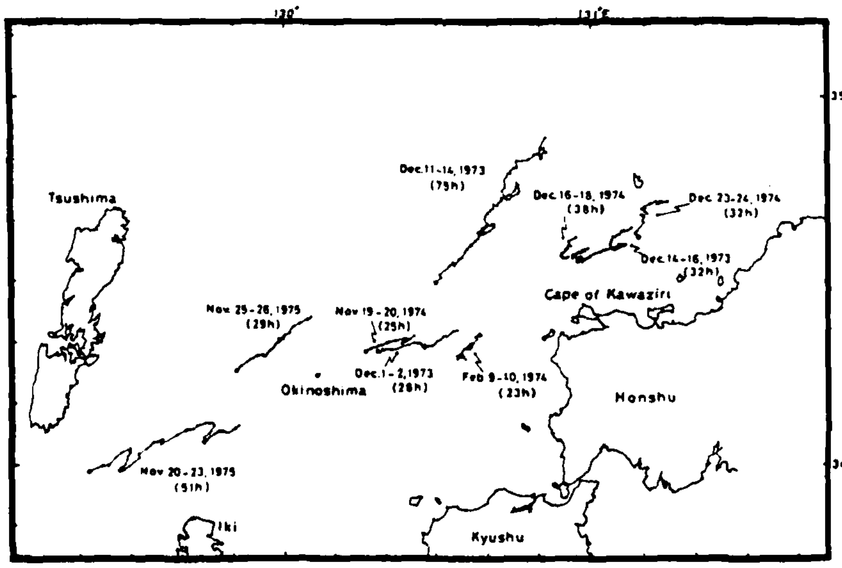
Choi, B.H., 1980. A tidal model of the Yellow Sea and the Eastern China Sea. Korea Ocean Research and Development Institute (KORDI) Report 80-02, 72 p.

A two-dimensional finite difference numerical model was developed to investigate primarily the distribution of the M2 constituent of the tide in the Yellow Sea and the East China Sea which includes the southern half of the Tsushima Strait. A uniform grid size of 1/5-degree latitude and 1/4-degree longitude was used, and the model calibration was performed against data at 56 tide gauge locations in the system. The computed results showed excellent agreement with data, with the error remaining at approximately 10% in amplitude and 10 degrees in phase.



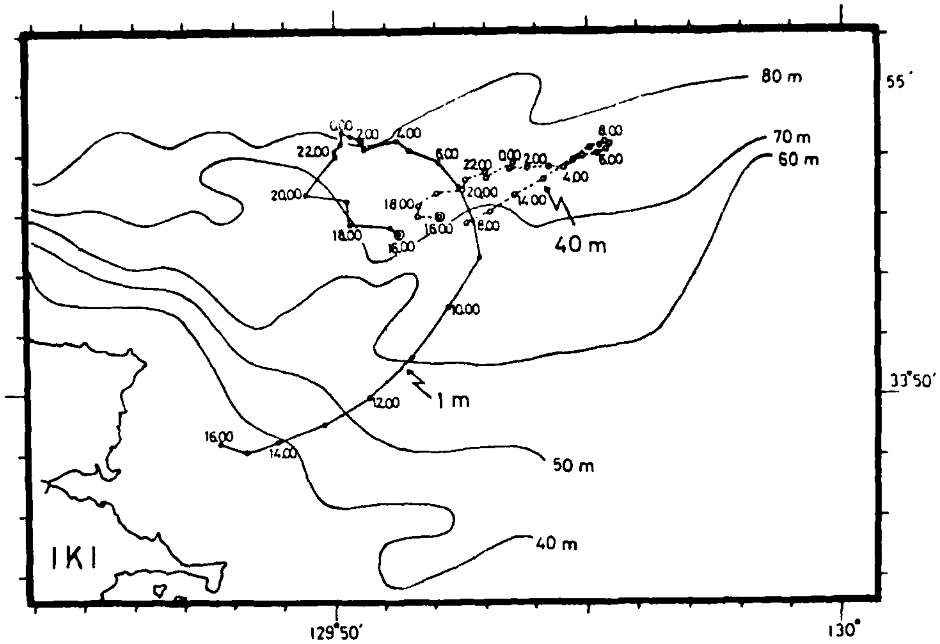
Trajectories of the current drogue in the Tsushima Straits and in the area east of the Straits (*summer*).

Figure 1. (Ogawa et al, 1979).



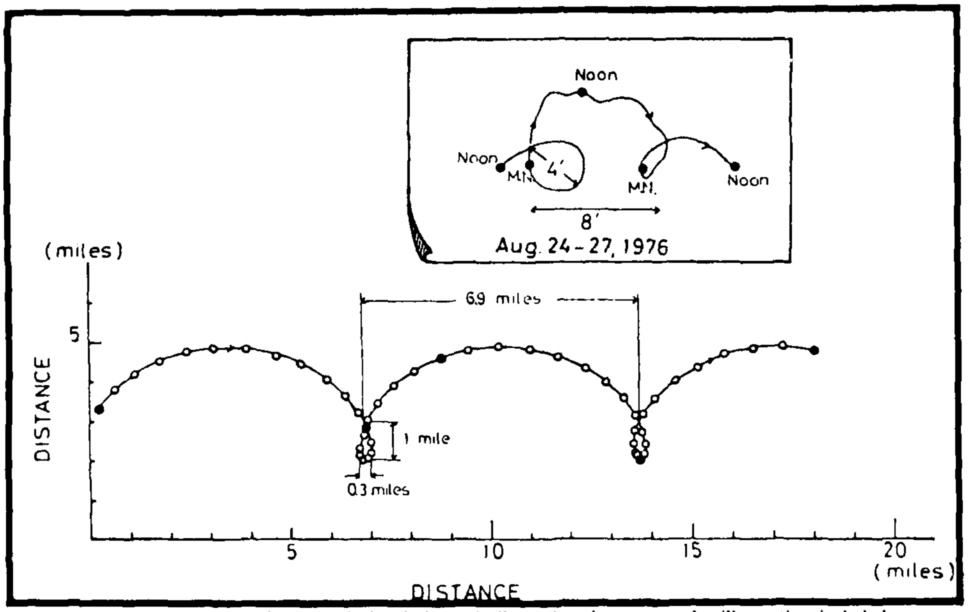
Trajectories of the current drogue in the Tsushima Straits and in the area east of the Straits.

Figure 2. (Ogawa et al, 1979)



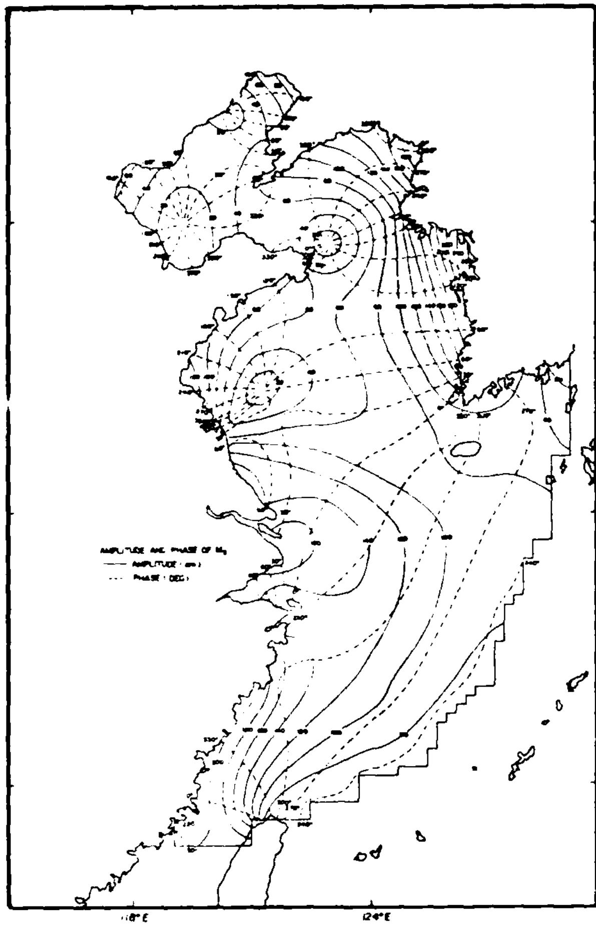
Trajectory of a deep current drogue in the north-eastern part of Iki Island im comparison with that of the surface drogue.

Figure 3. (Ogawa et al, 1979).



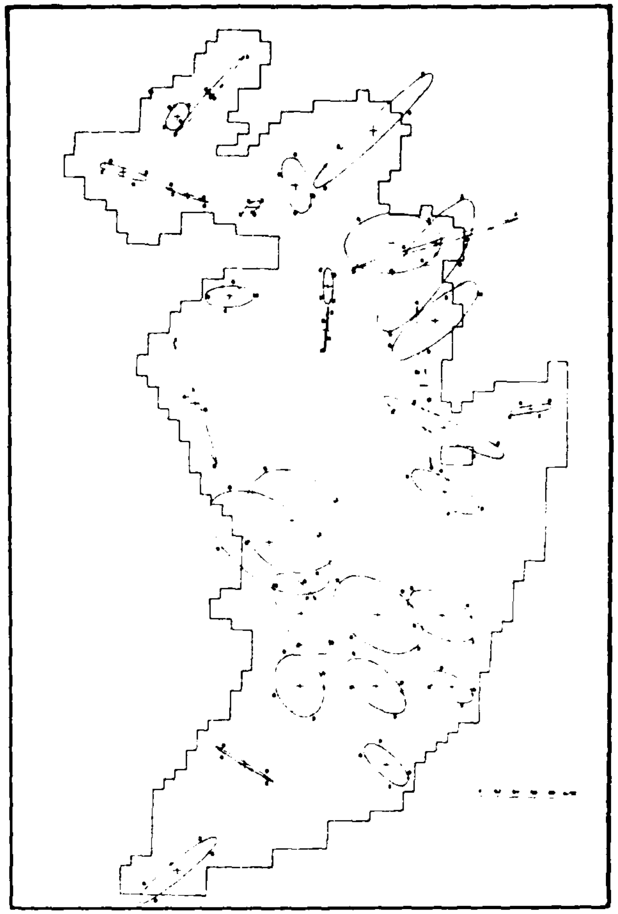
A drogue trajectory calculated theoretically as inertia current. An illustration included shows a real trajectory observed in the summer of 1976.

Figure 4. (Ogawa et al, 1979).



Computed M_2 tidal chart – the Yellow Sea and the Eastern China Sea.

Figure 1. (Choi, 1980)



Calculated M_2 tidal current ellipses in the Yellow Sea and the Eastern China Sea.

Figure 2. (Choi, 1980)

Science and Technology Agency, 1971. Report on the comprehensive study of the Sea of Japan (Japanese with English abstract). Special Report of Science and Technology Agency, Japanese Government, 98 p.

A 3-year program with participation of the Hydrographic Office, the Meteorological Agency, the Geological Survey, and the Fisheries Agency, was performed during 1968 through 1970. The Hydrographic Office in 1969 concentrated on the currents in the Tsushima Strait, occupying 39 stations in the strait for current measurements, of which two stations (one on each channel) were for measurements longer than 25 hours and the rest for 25 hours.

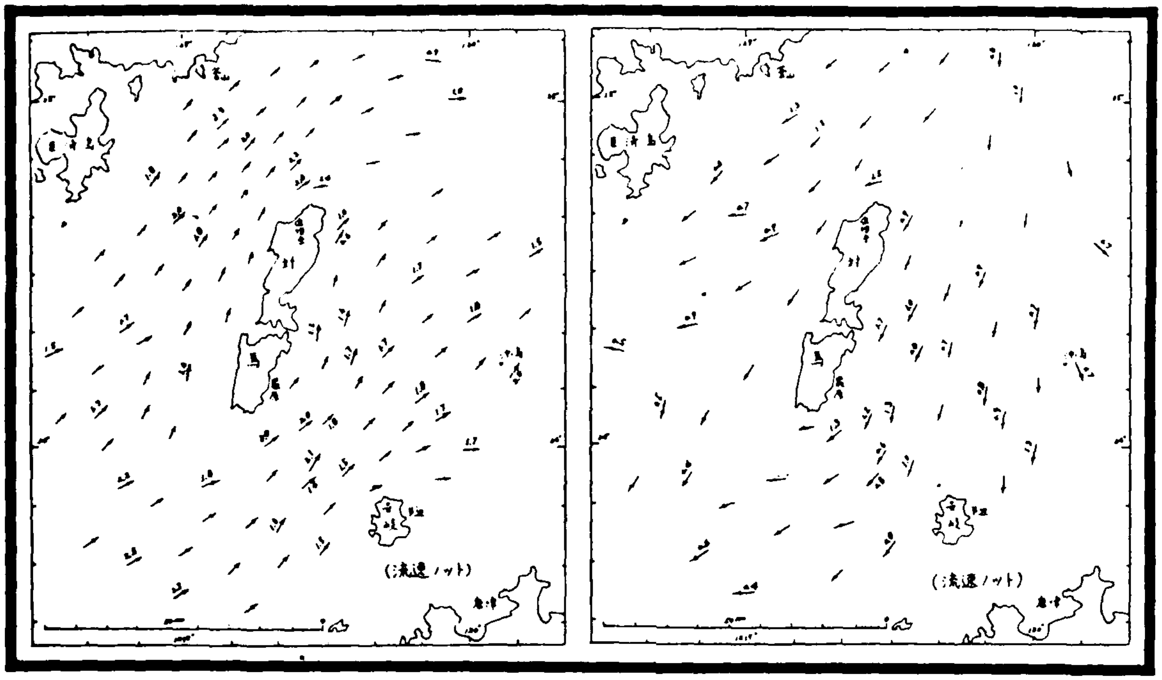


Figure 1. Tidal currents at Tsushima Strait.

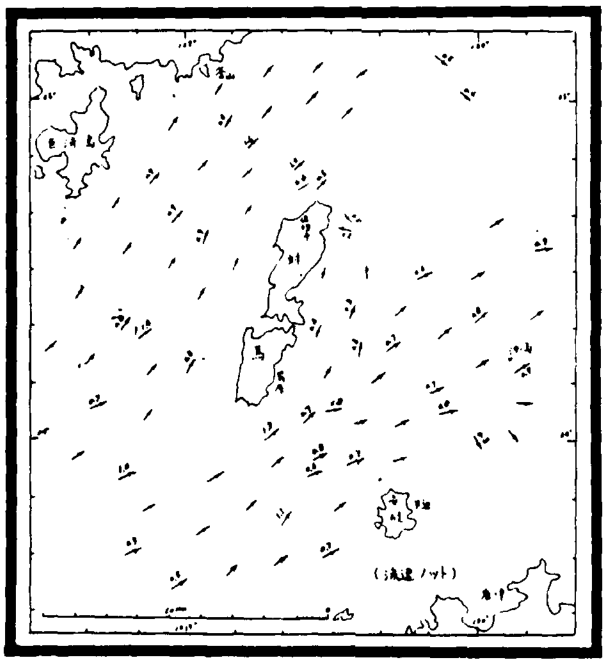


Figure 2.
Residual currents at Tsushima Strait.

(Science & Techn. Agency, 1971)

5.2 Circulation in the Sea of Japan

Uda, M., 1934. Hydrographical studies based on simultaneous oceanographical surveys made in the Japan Sea and its adjacent waters during May and June, 1932. Records of Oceanographic Works in Japan, 1(1), pp. 107.

This report describes part of the result of the most ambitious oceanographic study that took place in the prewar Japan, in which the Imperial Fisheries Experiment Station, with its Soyo Maru (202 GT) and a contingent of some 50 vessels from practically all the prefectures facing the Sea of Japan, conducted an "Issei Chosa" (simultaneous study) in the Sea of Japan, the Yellow Sea and the East China Sea. This study, following immediately the survey by the Imperial Marine Observatory's Syumpu Maru (1928-32), provided much of the knowledge on the Sea of Japan to mid-1950's, providing in particular a concept on the occurrence of three branches at the extension of the Tsushima Warm Current. Another paper emerged from this study relating to the survey results of October and November, 1933:

> Uda, M., 1936. Hydrographical studies based on simultaneous oceanographical survey made in the Japan Sea and its adjacent waters during October and November, 1933. Journ. Imperial Fish. Exp. Station, Vol 7, pp. 91-151.

The data was published in two semi-annual reports:

> Semi-annual report of Oceanographical Investigation, No. 50, 1932, pp. 390-397, and No. 51, 1933, pp. 260-270.

Figure 1 shows the survey lines (May-June, 1932), and Figure 2 the proposed general circulation pattern from this study.

The following excerpt from the summary section of the paper is of particular interest to sea strait hydrography:

> Masses of warm and salty water; which come into the Japan Sea through the Tusima Strait, flow out with a high velocity through the two straits of Soya and Tugaru. A cold and comparatively fresh water, belonging to the so-called Liman Current-System, flows in through Tartary (Mamiya) Strait, but in our opinion the quantity is very small, contrary to the inferences of Schrenck, Makaroff, etc.

In the seas adjacent to the southern Siberian Coast and North Tyosen, exists a source of relatively fresh and cold water, although the two large warm and cold water-masses keep up the two large vortical circulations, which are almost independent of eacn other, and mingle only on their boundary zones.

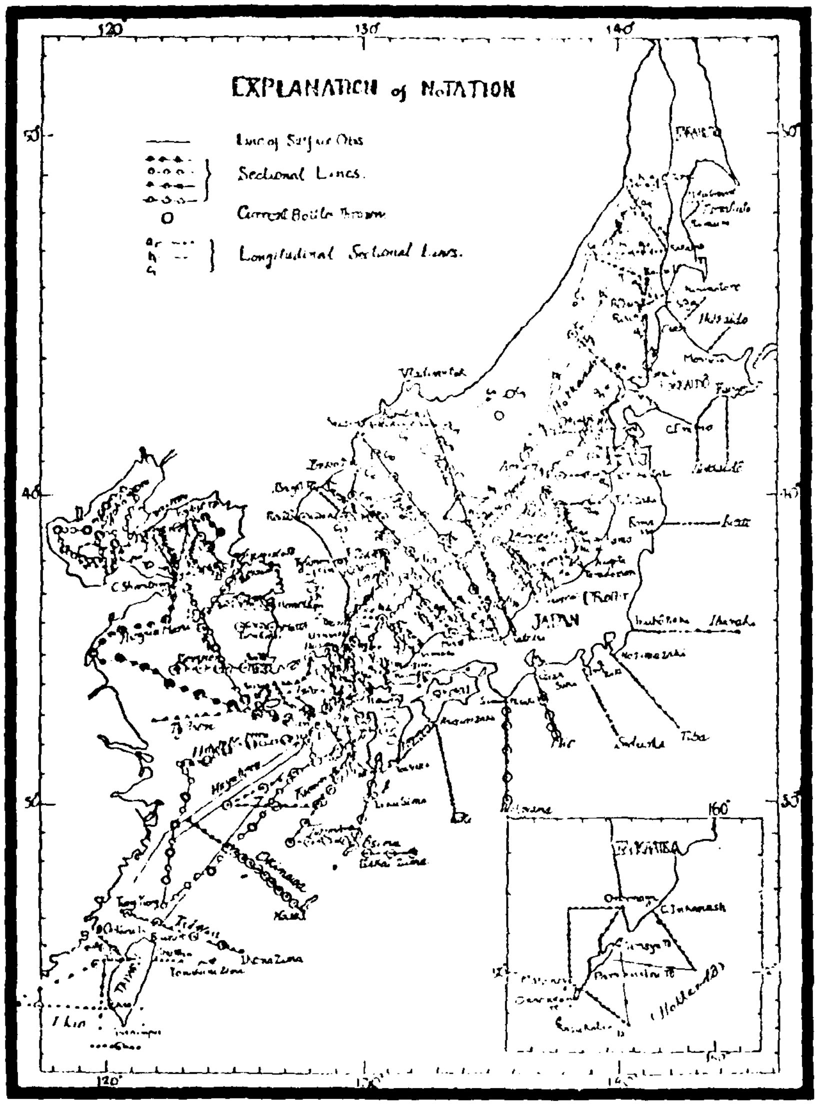
Observations of the course of the Tusima Current make it seem that the water of Warm Current-System, after its entrance through the Tusima Strait, spreads to the greater part of the Japan Sea and that owing to the earth's rotation, during the advance of the water in a NE direction a counter-current area is formed in its central part, when a water-mass constituting about 60-80% of the inflow passes through the Tugaru Strait from the Japan Sea to the Pacific Ocean.

We may therefore expect the stream-lines to be crowded at the west entrance of the Tugaru Strait, as in Fig. 35, although no exhaustive theoretical interpretation of it has yet been attempted.

North of the Tugaru Strait, the deverged stream-lines again converge at the entrance of Soya Strait, owing to the outflow of a large quantity of water through the latter strait.

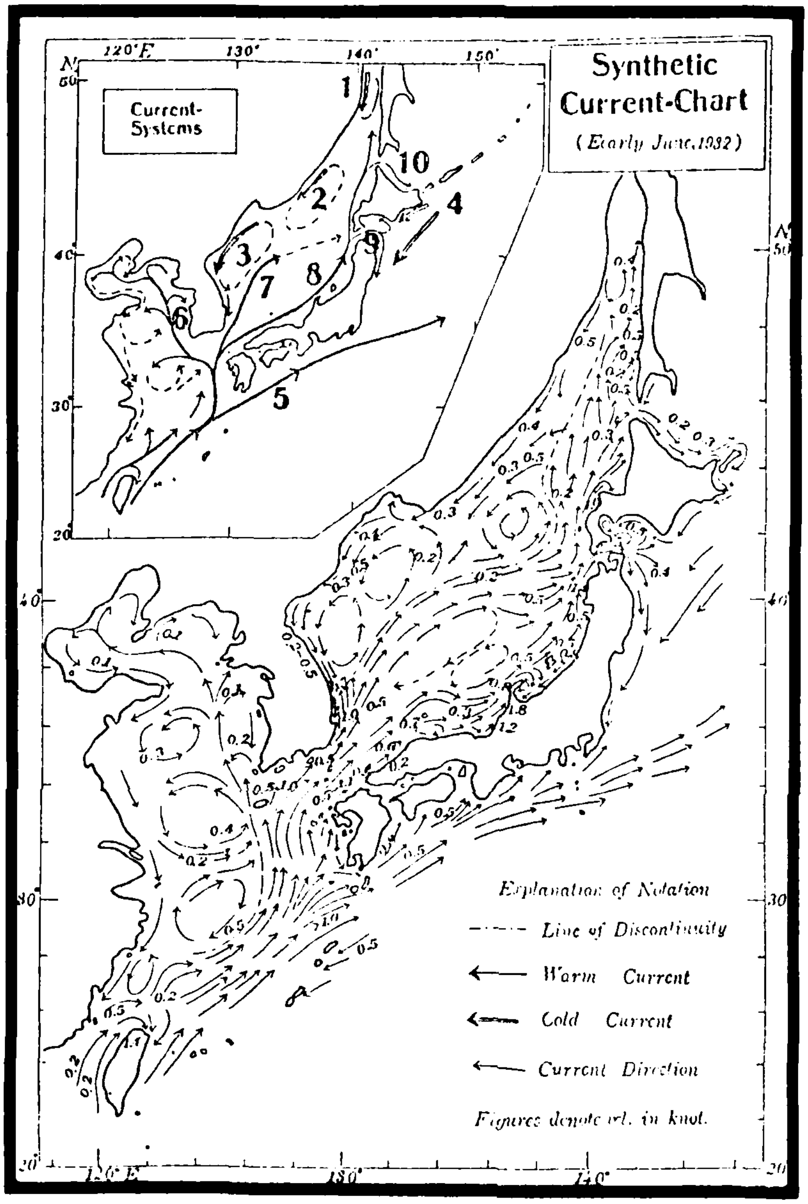
The south-going current along the continental side forms in such a way that, (1) the water adjacent to the coasts of southern Siberia and North Tyosen, under the influence of the deflecting force due to the earth's rotation, is deflected to the right, and (2) due to topographical restrictions, under the influence of East Tyosen Warm Current a counter-clockwise vortical current is induced.

As to the fundamental motive force that causes the inflow through the Soya and Tugaru Straits, some such agencies as difference in water pressure, tidal or meteorological-effect, or the combined effects of the current-systems in the northern Pacific Ocean, may be invoked to explain it, but the real nature of the mechanism is as yet unknown.



Oceanographic Sectional Lines and Stations. (Simultaneous Observations in May and June, [illegible]

Figure 1. Uda, 1934.



Currents in the Japan Sea and its Adjacent Waters in Early June, 1932.

1. Liman Cold Current
2. Cold Current along Siberian Coast.
3. North Tyôsen Cold Current.
4. Oyasiwo Cold Current
5. Kurosiwo Warm Current.
6. Warm Current in the Yellow Sea.
7. East Tyôsen Warm Current
8. Tsusima Warm Current
9. [illegible] Warm Current.
10. Sôya Warm Current.

Figure 2. Uda, 1934.

Tanioka, K., 1968. On the East Korean Warm Current. The Oceanographical Magazine, 20(1), pp. 31-38.

Characteristics of the East Korean Warm Current are elucidated from analysis of KFRDA data during 1960-64, CSK data during 1965-67, and data from three Japanese prefectural fisheries experiment stations facing the Tsushima Strait, i.e. Fukuoka, Yamaguchi and Shimane, during the same period. The author ascertains that East Korean Warm Current would move as far north as 40°N, beyond Ullung-Do, usually occurring in fall. The current axis is closer to the coast in winter and spring, but farther offshore in summer and fall. The northward volume transport is estimated to be about 3 Sv., but 80-90% appears to move back as a countercurrent occurring just east of it. Where a strong countercurrent makes a sharp anticyclonic turn nearer the Honshu coast, a mesoscale cold water mass is generated inside the bend.

Iida, H., 1972. On the shape of the sea surface along the coast of islands of Japan. The Oceanographical Magazine, 23(2), pp. 69-79.

The shape of the sea surface along the Japanese coasts was investigated on the basis of data from a total of 40 Japan Meteorological Agency tide stations. The bench mark elevations from the most recent first-class leveling work accomplished by the National Geographical Institute during 1963-68 was used to reduce the data at individual tide stations to a common datum (T.P.). The result shows that the sea levels along the Sea of Japan are highest than those along the Pacific coast. Along the Japanese coast, the sea level rises toward the northeast, reaching the highest value at Iwasaki in the downstream region of the Tsushima Warm Current. This, however, is consistent with the dynamic depth anomaly in the region.

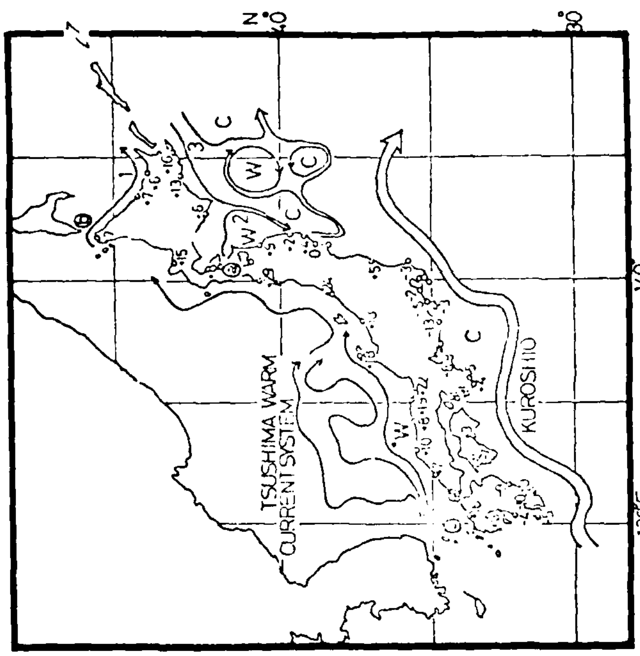


Fig. 4. Mean sea level in cm above T.P. from 1963 to 1968 and the pattern of the current system around Japan (the mean position of the axis of the Kuroshio was obtained by Watanabe, et al (1971)). 1; Soya warm current, 2; Tsugaru warm current, 3; Oyashio, a; Tsugaru straits, b; Soya straits, and c; Tsushima straits.

Figure 1. (Iida, 1972).

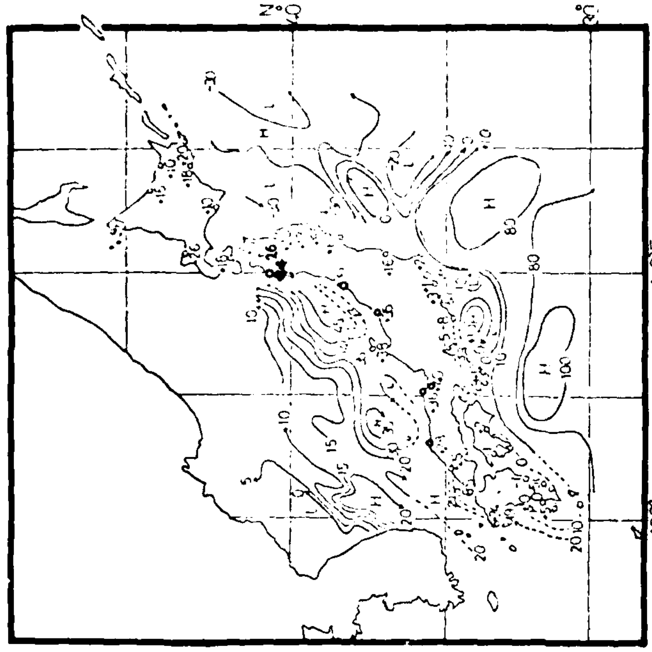


Fig. 7. Mean sea level in cm above T.P. and surface dynamic depth anomaly adjusted to it (above 1000db surface in the Pacific Ocean and 500db in the Japan sea) (summer, 1965).

Figure 2. (Iida, 1972).

Kawai, H., 1974. Historical models of ocean currents in the Sea of Japan (Japanese). In "Symposium on Tsushima Warm Current-Dynamics and Fisheries (Japanese)," Koseisha Koseikaku Press, Tokyo, Japan, pp. 7-26.

A number of models on the branching patterns of the Tsushima Warm Current extension past the Tsushima Strait are reviewed, beginning with the earliest Schrenck (1873) model through the earliest a 3-branch model by Suda and Hidaka (1932) and Uda (1934) to a 2-branch model(Tanioka, 1968; Moriyasu,1972) and a meander model (Naganuma, 1973). The author is in favor of a meander model and shows a striking similarity between the current pattern in the Sea of Japan and that of the Kuroshio meander. The geometrical scale ratio of the two patterns is about 2:1, which is in rough agreement with the ratio of the corresponding barotropic Rossby wave lengths.

References:

Schrenck, L.V., 1973. Stroemungs-verhaeltnisse in Okhotskschen u. Japanischen Meere u. in den zunaechst angrenzenden Gewaeessern. Mem. d. l'Acad. Imp. d. Sc., St. Petersburg, VII.

Suda, K. and K. Hidaka, 1930. The result of the oceanographic observation on board "Syumpu Maru" in the southern part of Japan Sea in the summer of 1928.

Part 1: Jour. Oceanography (Kaiyo Jiho), Imperial Mar. Obs., 2, pp. 1-73.

Part 2: Jour. Oceanography (Kaiyo Jiho), Imperial Mar. Obs., 2, pp. 155-264.

Suda, K. and K. Hidaka, 1932. The results of the oceanographical observations on board R.M.S. "Syumpu Maru" in the southern part of the Japan Sea in the summer of 1929.

Part 1: Jour. Oceanography (Kaiyo Jiho), Imperial Mar. Obs., 3(2), pp. 291-375.

Suda, K. and K. Hidaka, 1932. Results of the second oceanographical observation on board R.M.S. "Syumpu Maru" in the southern part of Japan Sea (July-September, 1929). Jour. Oceanography (Kaiyo Jiho), 3(2), pp. 329-330.

Suda, K., K. Hidaka, Y. Matsudaira, E. Kurashige, H. Kawasaki, and T. Kubo, 1932. The results of oceanographical observations on board R.M.S. "Syumpu Maru" in the principal part of the Japan Sea in the summer of 1930. Jour. Oceanography (Kaiyo Jiho), 4(1) pp. 38-40.

Tanioka, K., 1968. On the East Korean Warm Current (Tosen Warm Current). The Oceanographical Magazine, 20(1), pp. 31-38.

Moriyasu, S., 1972. The Tsushima Current. In "Kuroshio - Its Physical Aspects," ed. by H. Stommel and K. Yoshida, Univ. of Tokyo Press, pp. 353-369.

Naganuma, M., 1973. On the controversy of the third branch of the Tsushima Warm Current (Japanese). Nissuiken Laison News, Japan Sea Region Fisheries Research Laboratory, No. 266, pp. 1-3.

Yoon, J-H., (1974). Numerical investigations of the circulation in the Japan Sea - Branching of the Tsushima Current. Ph.D. dissertation submitted to Geophysical Institute, Faculty of Science, Univ. of Tokyo, 132 p.

Computer simulation is performed to investigate the branching mechanism of the Tsushima Warm Current in the Sea of Japan. The study finds that two branches are formed: a western branch corresponding to East Korean Warm Current which results from the Beta-effect as well as from differential heating in the Sea of Japan, and an eastern branch along the Honshu coast which is topographically controlled. The model predicts formation of cold water and a narrow boundary current off the Siberian coast in winter, and of the polar front across the Sea of Japan associated with seasonally varying atmospheric conditions. See Figures 1 and 2.

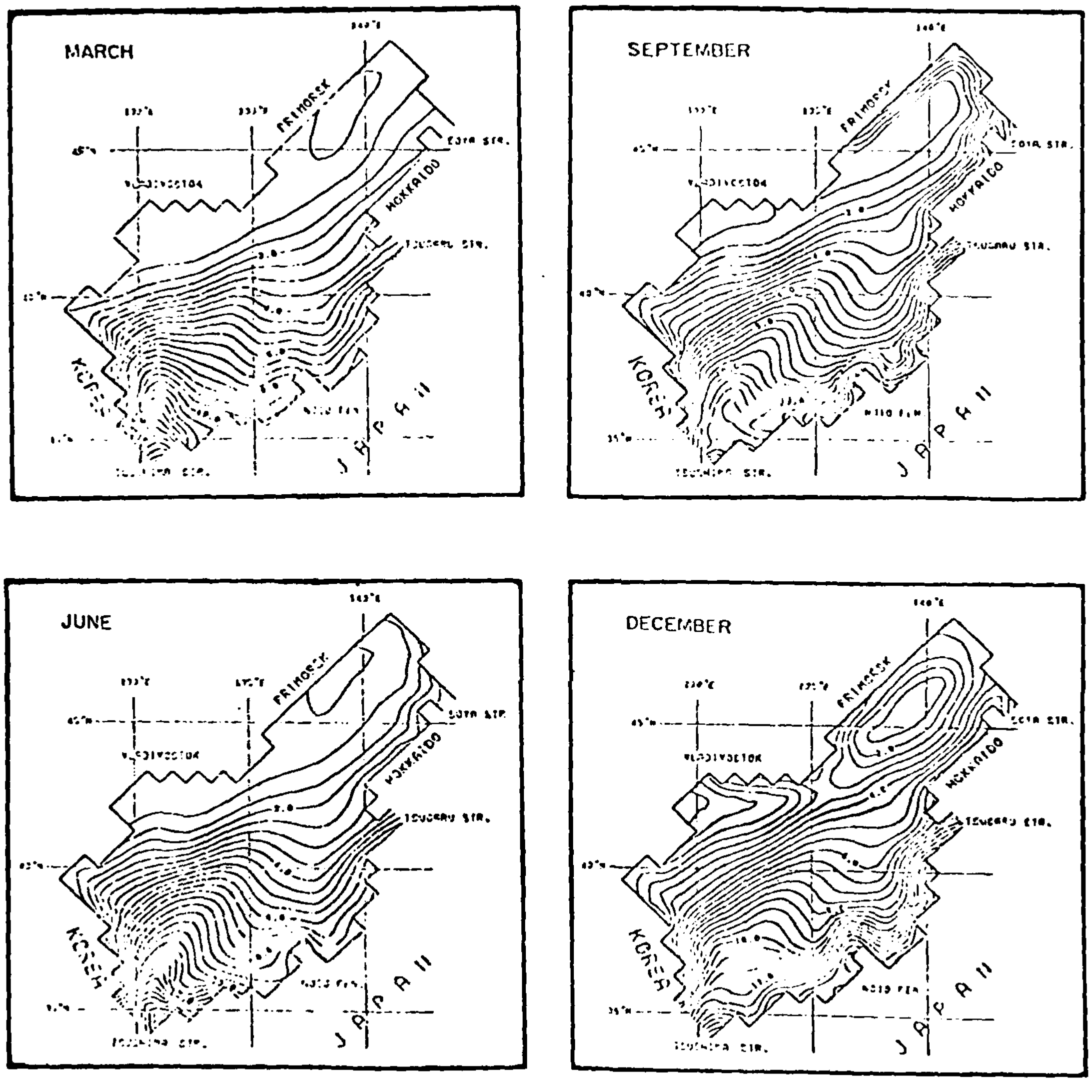


Figure 1. Calculated temperature field at 125-meter depth (Yoon, 1979). Notice the formation of cold water off Primorsk in March, and a sharp temperature gradient in September-December where a narrow boundary current is also predicted during the same season (Figure 2). Notice also a distinct temperature gradient along Honshu in September-December which also corresponds to a well-developed boundary current.

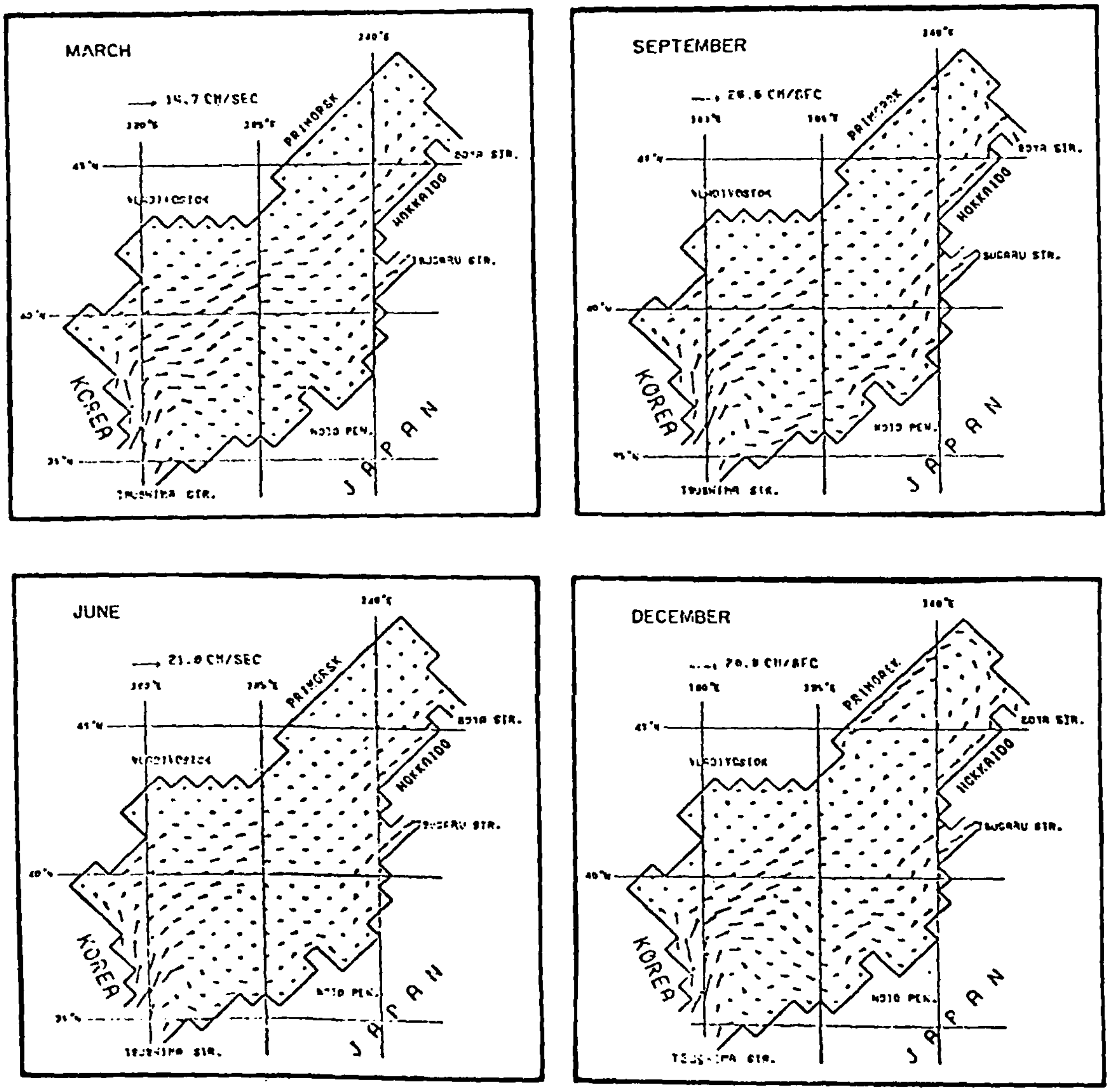


Figure 2. Calculated velocity field at 15-meter depth (Yoon, 1979). Notice the formation of a narrow boundary current off Primorsk in September-Decemter (see also Figure 1). A boundary current along Honshu becomes distinct in September-December.

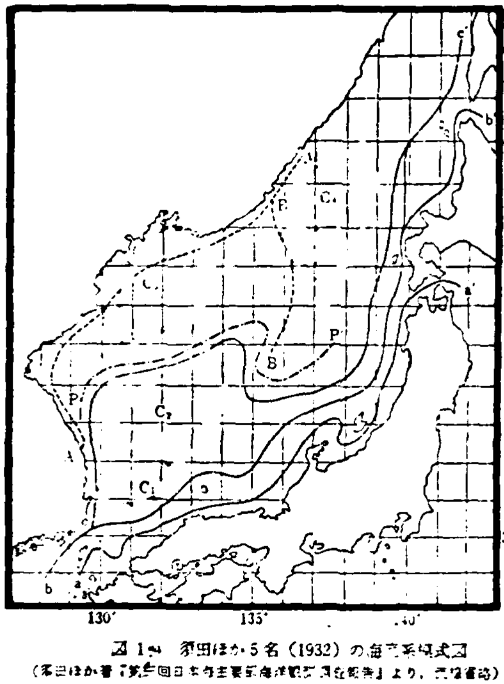


Figure 1. Current patterns proposed by K. Suda and others from the data obtained during the 3rd Syumpu Maru cruise in 1930.

a–a' First branch, Tsushima C.
b–b' Second branch, Tsushima C.
c–c' Third branch, Tsushima C.
A–A' Liman C.
B–B' Liman C.
P–P' Polar front
C1, C3 & C4 Cyclonic gyre
C2 Anticyclonic gyre

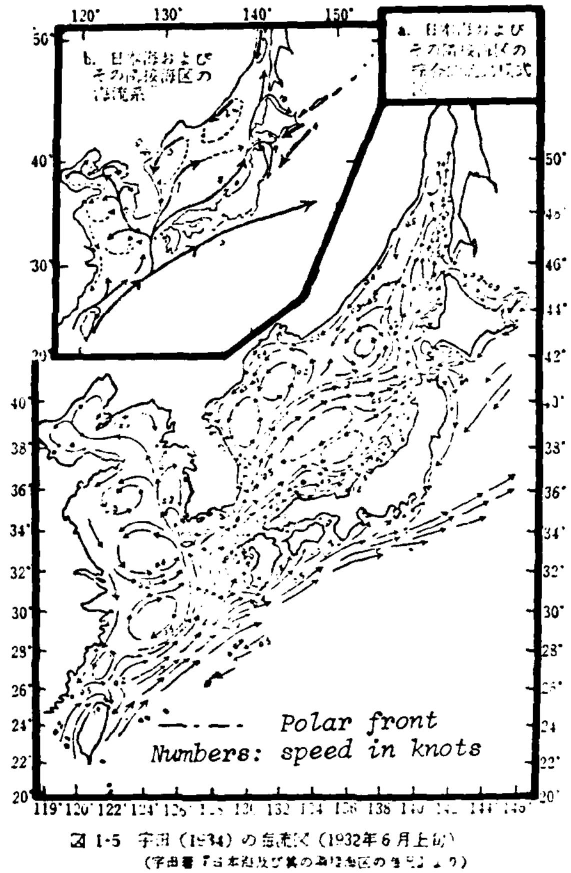


Figure 2. Current patterns for June, 1932, deduced by M. Uda (1934).

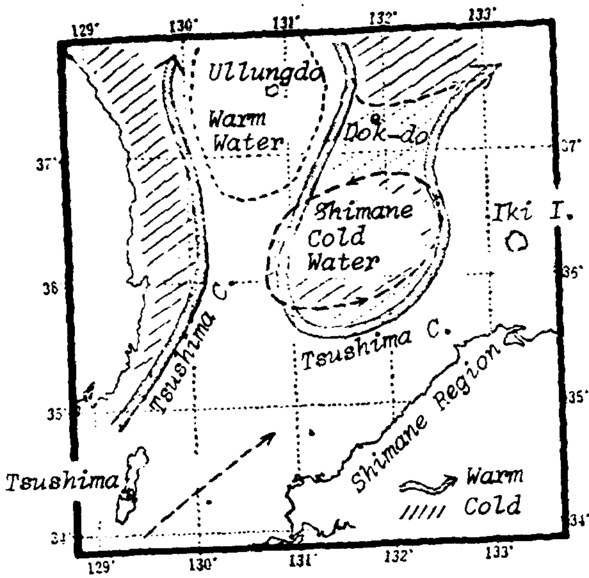


図 1-8 小川 (1971) の海況模式図 (小川著『日本海西南海域の海況』より)

Figure 3. Relationship between the meander of Tsushima Warm Current and warm and cold water masses. From Ogawa, Y., 1971. Oceanographic conditions in the southwestern part of Japan Sea. Rep. Yamaguchi Prefecture Outer-Sea Fisheries Experiment Station, 42 p.

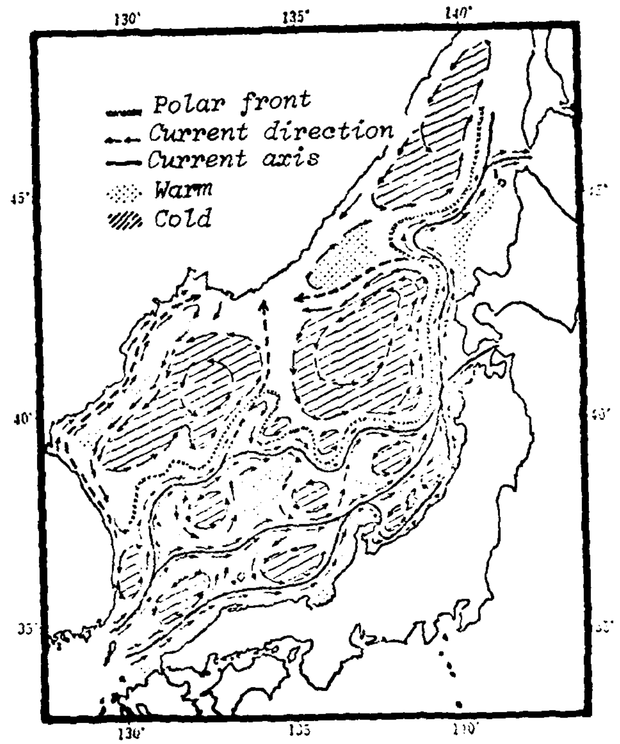


図 1-6 長沼 (1972) の海況図

Figure 4. Current patterns deduced from fishery oceanographic studies on squid fishing grounds in Japan Sea. From Naganuma, M., 1972. Discussion on the existence of the third branch of Tsushima Warm Current. Japan Sea Fish. Res. Lab. Newsletter, No. 266, 1-3.

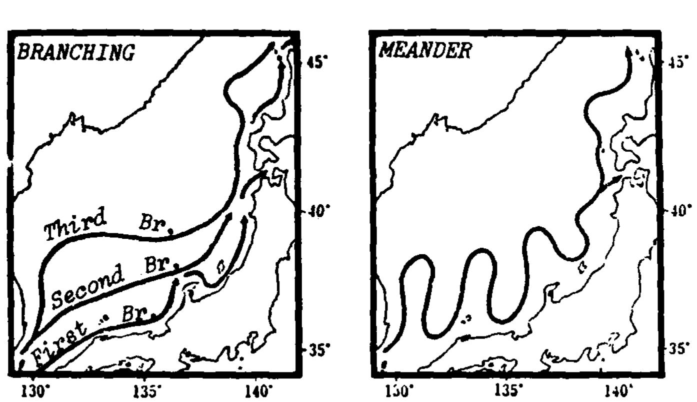


図 1·7 日本海の対馬暖流系模式図の分類（長沼, 1973；日水研連絡ニュース266号より）

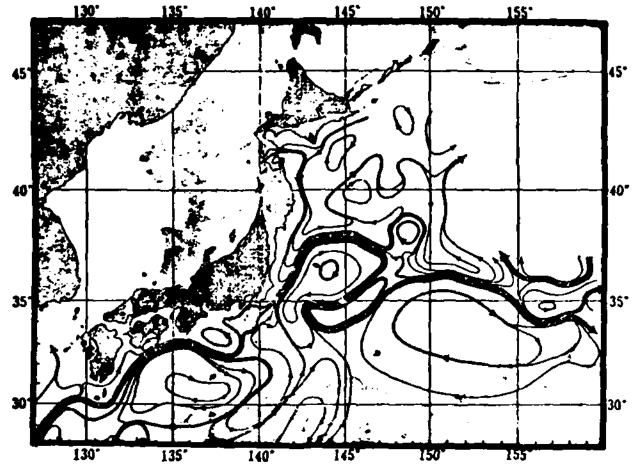


図 1·9 黒潮続流系模式図（川合, 1972 a,b）の日本海南西部への[illegible]

Figure 5. Schematic diagram showing contrasting concepts of current patterns at the extension of Tsushima Warm Current in Japan Sea. From Naganuma, M., 1972. Discussion on the existence of the third branch of Tsushima Warm Current. Japan Sea Fish. Res. Lab. Newsletter, No. 266, 1-3.

Figure 6. Similarities between the current patterns at Kuroshio extension and those of Tsushima Warm Current in Japan Sea. Topography was expanded to twice in size, rotated 24 degrees anti-clockwise, and transferred latitudinally. The current patterns shown are those for Kuroshio extension. From Kawai, H., 1972. The Kuroshio Extension. In Kuroshio-Its Physical Aspects, edit. by H. Stommel and K. Yoshida, Univ. of Tokyo Press 235-352, and Kawai, H., 1972. Descriptive Oceanography of Kuroshio and Oyashio. In Physical Oceanography II, Tokai Univ. Press, 129-321.

Nakano, M. and S. Yamada, 1975. On the mean sea levels at various locations along the coast of Japan. Journ. Oceanographical Soc. of Japan, vol. 31, pp. 71-84.

Variations of annual mean sea levels at a total of 55 stations between 1953 and 1970 are analyzed to determine their relationship with meteorological and oceanographical conditions. The effect of tectonic movement was found to be less than 10 mm/year in 90% of the stations, and the effect of atmospheric pressure fluctuation on the order of several cm. After subtracting these two effects, the mean sea level is found to be higher along the coast on the Sea of Japan, the west coast of Kyushu and the coast of Hokkaido than on the Pacific coasts. Other suspected causes are the deflecting force due to the earth's rotation on currents and the steric effect.

Minato, S. and R. Kimura, 1980. Volume transport of the western boundary current penetrating into a marginal sea. Journ. Oceanographical Soc. of Japan, Vol. 36, pp. 185-195.

The paper is a numerical test of a concept considering the inflow into the Tsushima Strait and the outflow through the Tsugaru Strait as resulting from the pressure difference between the two straits associated with the western boundary current of the subtropical gyre in the North Pacific. The computation is based on a linear, steady and barotropic model on a Beta plane with bottom friction, width and depth of the straits as variable parameters. The result shows that in the absence of bottom friction, the inflow through the Tsushima Strait is controlled mainly by the external conditions, i.e. the wind stress driving the western boundary current in the open ocean and the relative positions of the two straits. In the care of a finite value of bottom friction, the main controlling factors are the ratio of the depth of the Sea of Japan to that of the open ocean as well as the width of the sea straits. In both cases, the transport is driven by the average pressure gradient between the two sea straits. Using the model, the authors estimate that the volume transport through the Tsushima Strait represents about 2% of the transport of the Kuroshio as previously ascertained by Moriyasu (1972).

5.3 Tsugaru Strait

Hikosaka, S., 1953. On the ocean currents (non-tidal currents) in the Tsugaru Strait. (Japanese with English abstract). Hydrographic Bulletin No. 39, pp. 279-285.

The report summarizes the results of two cruises in the summer (June 1 - August) of 1951 and 1952 by the Japan Hydrographic Offices No. 4 Kaiyo Maru (200 GT), No. 1 Tenkai Maru (100 GT), and a supporting ship. Part of a previous cruise performed in 1941 is also analyzed. Twenty-four-hour measurements of currents were performed at about 100 positions. The residual component of the measured currents (non-tidal), which is indicative of net volume transport of the Tsushima Warm Current into the Tsugaru Strait, exhibited remarkable fluctuation at semi-monthly to monthly periods. This may be due to the fluctuation of either the strength of the inflow or the path of the current axis, or both. Measured current speeds in the channel displayed a good geostrophic relationship with the water level differences across the channel (between Tappi and Shirakami).

Akagawa, M., 1954. On the oceanographic conditions of the north Japan Sea (west off the Tsugaru Straits) in summer (Part 1) (Japanese with English abstract). Journ. Oceanographical Soc. of Japan, 10(4), pp. 189-199.

Several distinct water masses are recognized in the region adjacent to the entrance of the Tsugaru Strait based on the hydrographic data in the summer of 1950-53. These water masses are:

C: Coastal water with low chlorinity and high D.O. and nutrient salts.

T(S): Occupying the surface layer (less than 25 m) of the Tsushima Warm Current, this water mass extends to the west to form pronounced rips at the boundary with the Liman cold current. This boundary, occurring along what is known as the Japan Sea Polar Front, is recognized about 60 miles off Gongen Zaki in summer. Characteristic temperature is over $20^{o}C$ and salinity less than $18.90^{o}/oo$. The water mass T(S) consists of 3 sub-masses: T(Sc), T(SB) and T(SL), depending upon the routes of the branches of the Tsushima Warm Current in the Sea of Japan before they converge at a point off Gongen Zaki.

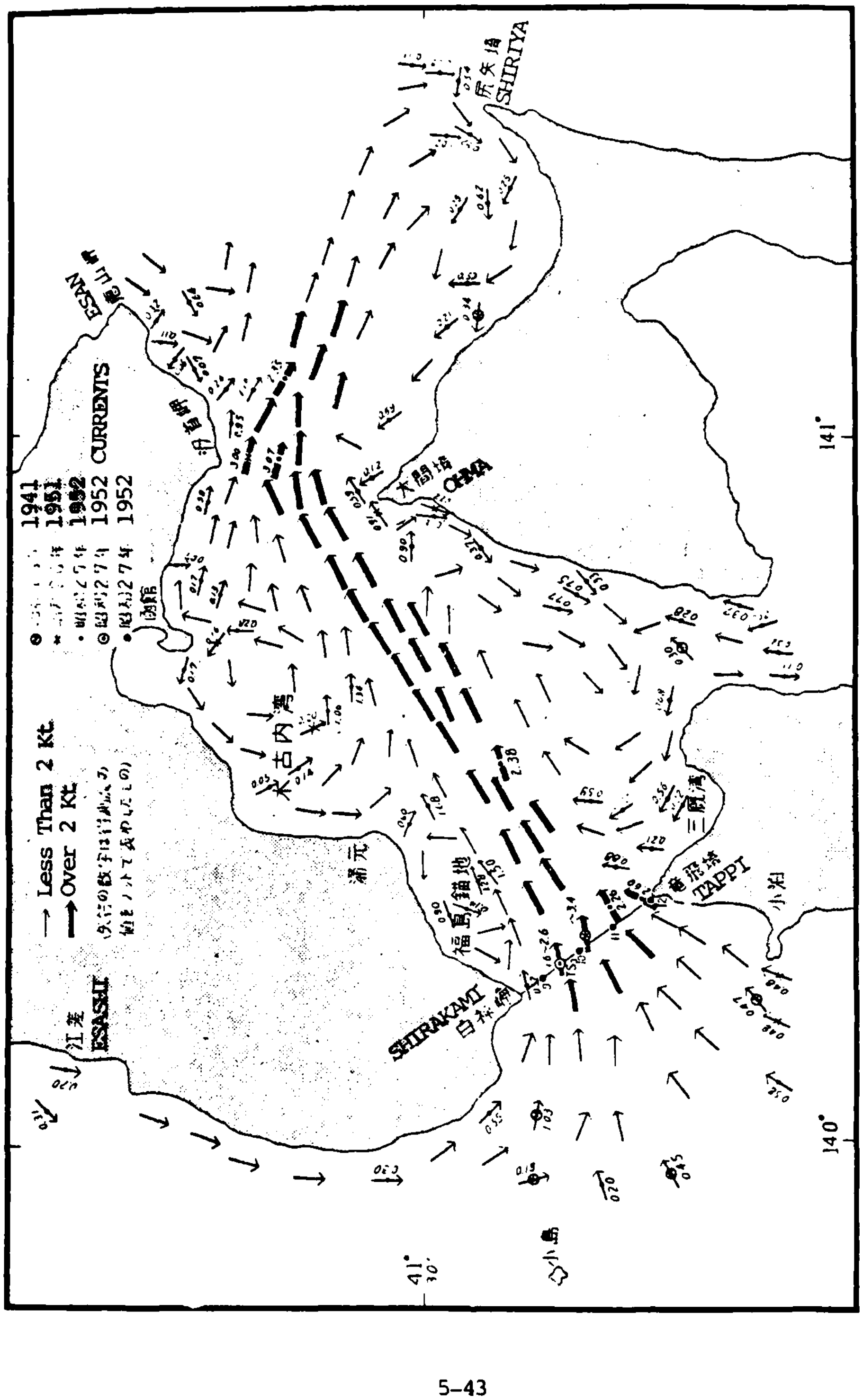


Figure 1. (Hikosaka, 1953).

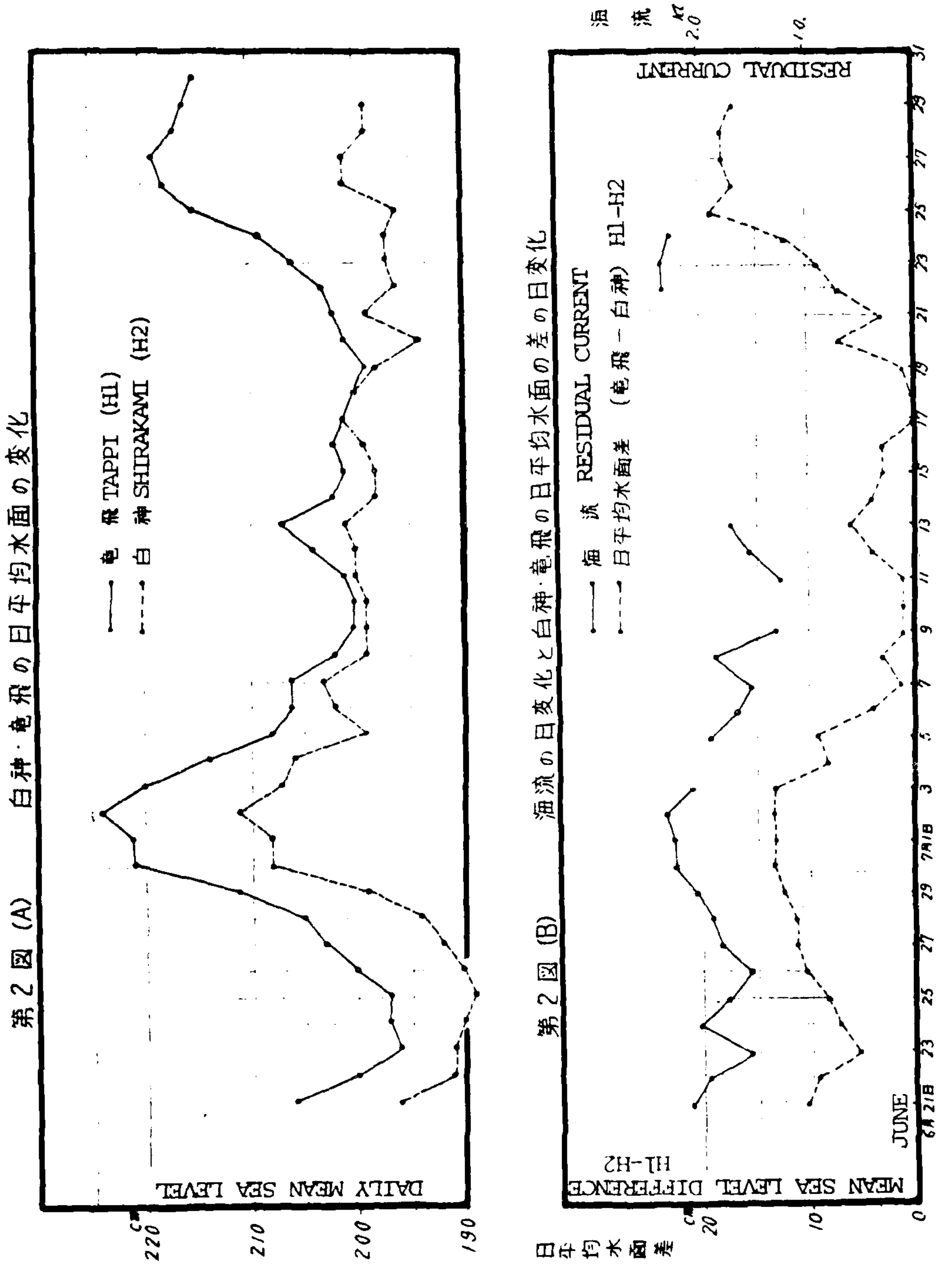
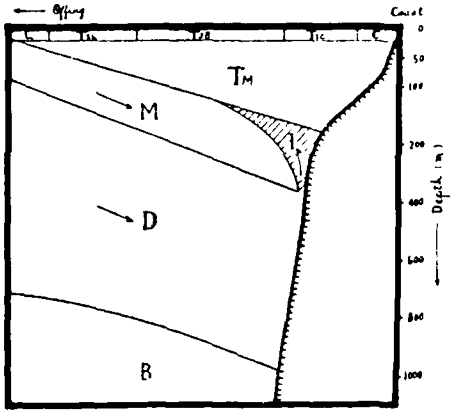


Figure 2. (Hikosaka, 1953).



Schematic representation of water mass stratification.

Figure 1.
(Akagawa, 1954).

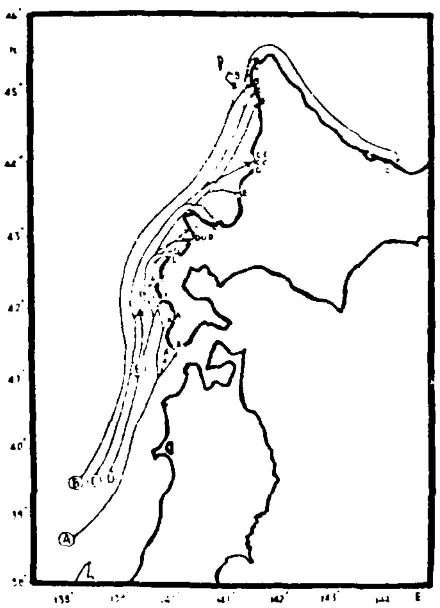


Figure 1.
(Akagawa, 1955)
Trajectories of
drift bottles.

T(M): A mid-layer mass and a principal constituent of the Tsushima Warm Current, lying beneath T(SB) between 50 and 75 m from the surface, characterized by 15°C and 19.00 °/oo.

L: Surface water of the Liman Current, characterized by 16-17°C and 18.7 °/oo adjacent to the Polar Front.

M: Sometimes called "mid water", this water mass is located between 200 and 250 m from the surface in the Tsushima Warm Current region. It is characterized by 3 - 4°C and around 18.80 °/oo.

B: Japan Sea bottom water, lying usually below 1000 m. Characteristic temperature is around 0.1°C and salinity around 18.85 °/oo at the depth of 1000 m.

Akagawa, M., 1955. On the oceanographical conditions of the north Japan Sea (west of the Tsugaru-Straits) in summer (Part 2) (Japanese with English abstract). Journ. Oceanographical Soc. of Japan, 11(1), pp. 5-11.

Trajectories of the drift bottles released in the Tsushima Warm Current indicated that only the water masses T(SC), C and part of T(SB) would be entrained into the Tsugaru Strait, the rest continuing the northward movement with the Tsushima Warm Current.

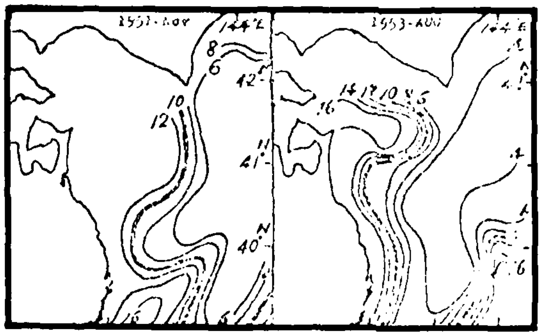
Yasui, Z. and K. Hata, 1960. On the seasonal variations of the sea conditions in the Tsugaru Warm Current region. Bull. Hakodate Marine Observatory, No. 7, pp. 1-10.

The authors review existing data and literature to discuss the volume transport into the Tsugaru Strait, sea conditions off the eastern opening, and relations between the sea conditions off the western and eastern openings. They find that the volume transport [illegible] the Tsugaru Strait varies from 50 to 100 percent of the [illegible] Tsushima Warm Current, averaging about 70%. At the [illegible] opening, off Shiriya Saki, the transport of the Tsugaru Warm [illegible] would vary seasonally from a minimum of 0.2 - 3.6 Sv in [illegible] to a maximum of 1 - 7.7 Sv in August-November. The [illegible] considerably fluctuates in pattern depending largely

Transports in $10^6 m^3/sec$ in the sea east of Shiriyazaki.

Year \ Season	Feb.-Mar.	May	Aug.	Nov.
1950	0.3	1.3	—	2.3
51	—	0.6	—	2.8
52	—	2.6	6.3	6.3
53	0.3	0.2	7.7	—
54	1.1	1.6	2.6	1.0
55	0.2	2.0	6.2	2.8
56	1.5	2.6	4.7	7.4
57	2.2	2.0	2.4	2.8
58	3.6	0.4	2.9	5.0

Table 1. (Yasui & Hata, 1960).



Mean temperature distribution in the layers from 0 to 200m in the sea region east of the Tsugaru Straits.

Figure 1. (Yasui & Hata, 1960).

upon the intensity of the Kuroshio and other undetermined ambient conditions. The eastward extension of the outflowing Tsugaru Warm Current could be large even when the volume transport was small (Nov. 1951 and Aug. 1958).

Kubota, T. and K. Iwasa, 1961. On the currents in Tsugaru Strait (Japanese with English abstract). Hydrographic Bulletin No. 65, pp. 19-26.

Currents through the Tsugaru Strait were investigated using the electric potential difference induced in the submarine telephone cable as well as GEK and drogues in 1959 and 1960. A calibration test showed that an induced electric potential difference of 100 mV was equivalent to about 1 knot at the western entrance of the strait. Comparison between GEK-measured surface currents and the recorded electric potential difference showed little correlation between the two parameters. An interesting correlation was recognized between the induced electric potential difference and the atmospheric pressure difference between Hakodate and Hachinoe.

Hakodate Marine Observatory, 1961. Report of the oceanographic conditions in the Tsugaru Straits in the period from 1943 to 1958 (Japanese with English abstract). Bull. Hakodate Marine Observatory, vol. 8, 62 p.

Variation in strength of the eastward flowing warm current in the Tsugaru Strait was investigated on the basis of data collected at 10-day intervals over a 15-year period between 1943 and 1958 on board a cross-channel ferry boat. The report consists of four technical chapters dealing with water temperature and chlorinity, surface microplankton,chemistry, and relationship between the hydrography of the Tsugaru Strait and that off the Sanriki coast.

電位差と気圧差との関係

Induced electric potential difference and atmospheric pressure difference in Sep.~Oct., 1959

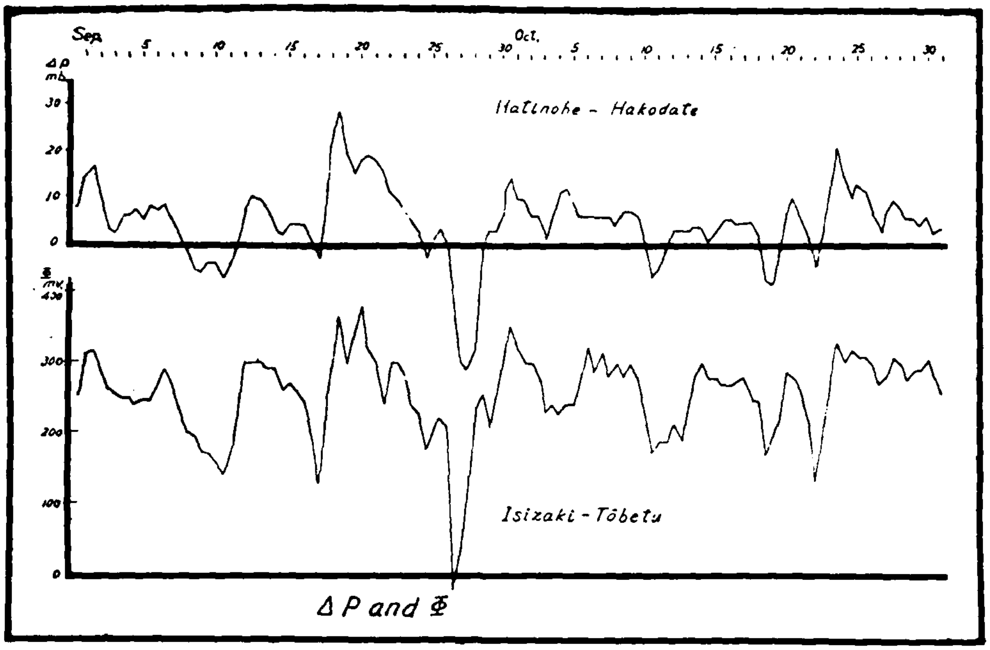
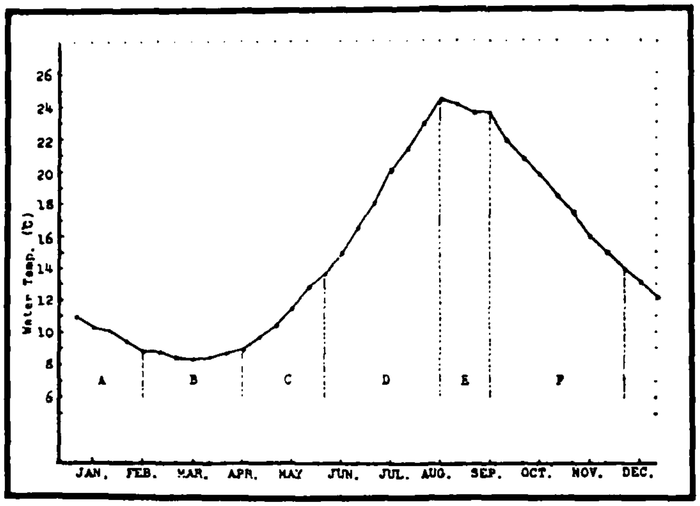
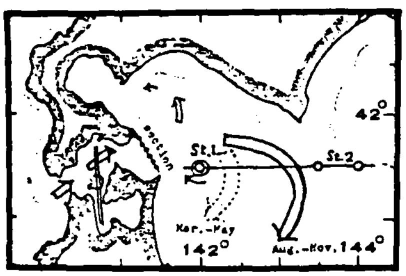


Figure 1. (Kubota & Iwasa, 1961).



Annual variation of mean maximum temperature of surface water in the Tsugaru Straits for 1943 to 1958.
A : Last stage of temperature dropping B : Minimum stage
C : First rising stage D : Linearly rising stage
E : Maximum stage F : Linearly dropping stage

Figure 1. (Hakodate Marine Observatory, 1961).



Showing the location of oceanographical observation station and section. Double arrow represents schematically the current system.

Figure 2. (Hakodate Marine Observatory, 1961).

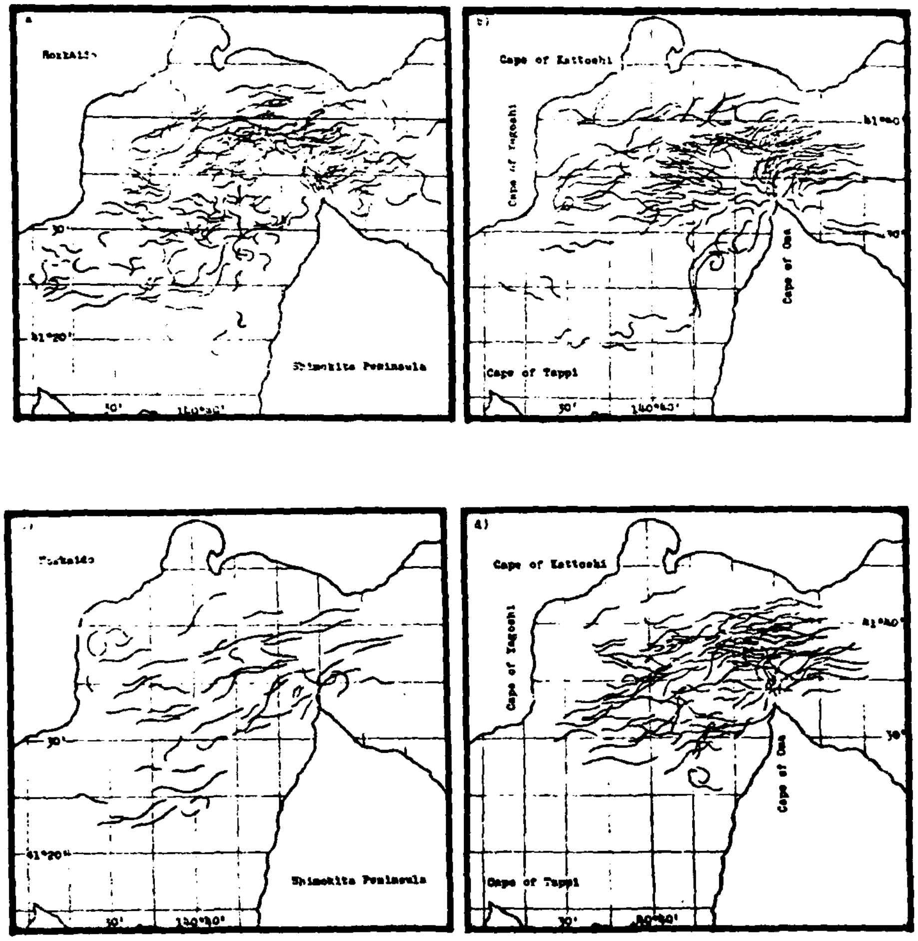


Figure 3.

Distributions of current-rips shown as rader echoes on the PP I scope photographs which were taken once a day in the period from Aug.4 through Sept.22, 1962 at Mt. Hakodate weather-rader Station. Fig.a), b),c) and d) are the distributions of current-rips echoes collected from the photographs taken in the periods of the flood, the high-water, the ebb and the low-water, respectively, of tide at Hakodate.

(Hakodate Marine Observatory, 1964)

Science and Technology Agency, 1971. Report on the comprehensive study of the Sea of Japan (Japanese with English abstract). Special Report of Science and Technology Agency, Japanese Government, 98 p.

A 3-year program with participation of the Hydrographic Office, the Meteorological Agency, the Geological Survey, and the Fisheries Agency, was performed during 1968 through 1970. In 1970, the Hydrographic Office performed current measurements in the Tsugaru Strait, occupying 16 stations. The Japan Meteorological Agency in October-November, 1970 conducted an ambitious 5-ship joint study of the Tsugaru Strait with participation of Ryofu Maru (JMA Hqs), Kofu Maru (Hakodate M.M.O.), Shumpu Maru (Kobe M.M.O.), Chofu Maru (Nagasaki M.M.O.) and Seifu Maru (Maizuru M.M.O.). A comprehensive range of data on the Tsugaru Strait and its adjacent areas emerged from this joint cruise.

Hata K., 1973. Variations in hydrographic conditions in the seas adjacent to the Tsugaru Straits (Japanese with English abstract). J. Meteor. Res., 25, pp. 467-479; also Bull. of Hakodate Marine Observatory, No. 18, 1975, pp. 17-29.

The study concerns itself with estimation of volume transport through the Tsugaru Strait on the basis of the entire range of hydrographic data obtained by the Japan Hydrographic Office, the Fisheries Research Laboratories (and prefectural fisheries experiment stations), and the Meteorological Observatories between 1933-1967 in an area bounded by 40 - 40.5N and 141 - 143.25E. The paper also gives an extensive literature review on various effects affecting the volume transport through the Tsugaru Strait. The transport through the Tsugaru Strait varies by one order of magnitude between about 5 and 0.5 Sv. Among the principal factors controlling the transport are: the occurrence of warm water masses detached from the Kuroshio close to the Sanriku coast (in the Pacific Ocean) which would cause a setup, reducing the water level difference between the Japan Sea and Pacific sides of the Strait (as in 1954, and 1967), disturbances due to typhoon on the Pacific side, mid-latitude cyclones which would cause a setup as the inflow side of the Strait in the Japan Sea, and the volume transport of the Tsugaru Warm Current arriving at the Tsugaru Strait. The ratio of the transport through the Tsugaru Strait relative to the arriving volume is also a function of the transport itself. The ratio was as high as 83%

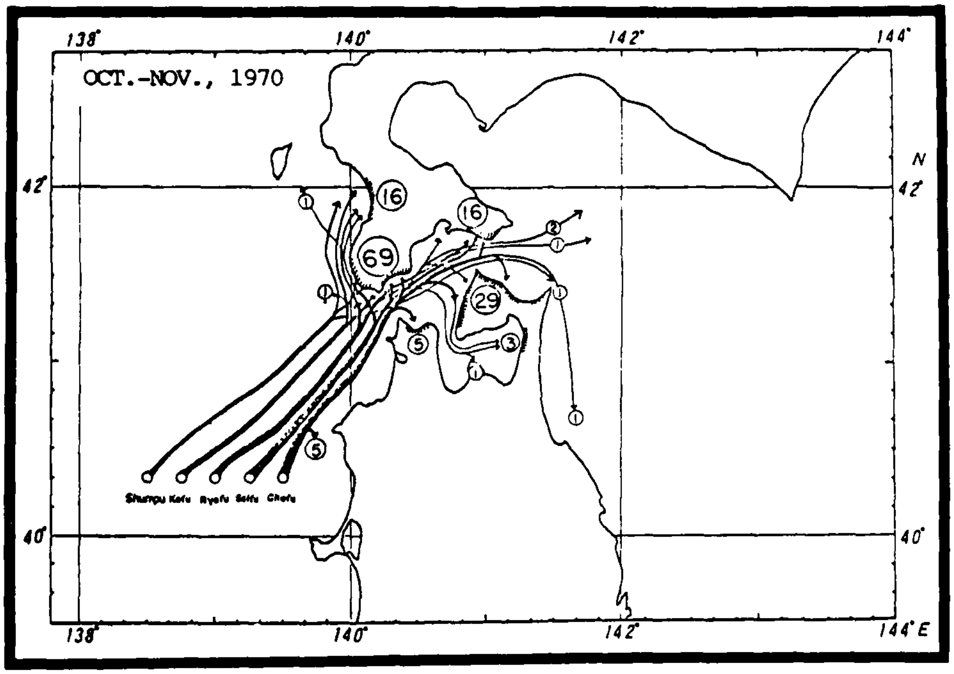


Figure 1. Drift bottle trajectories.

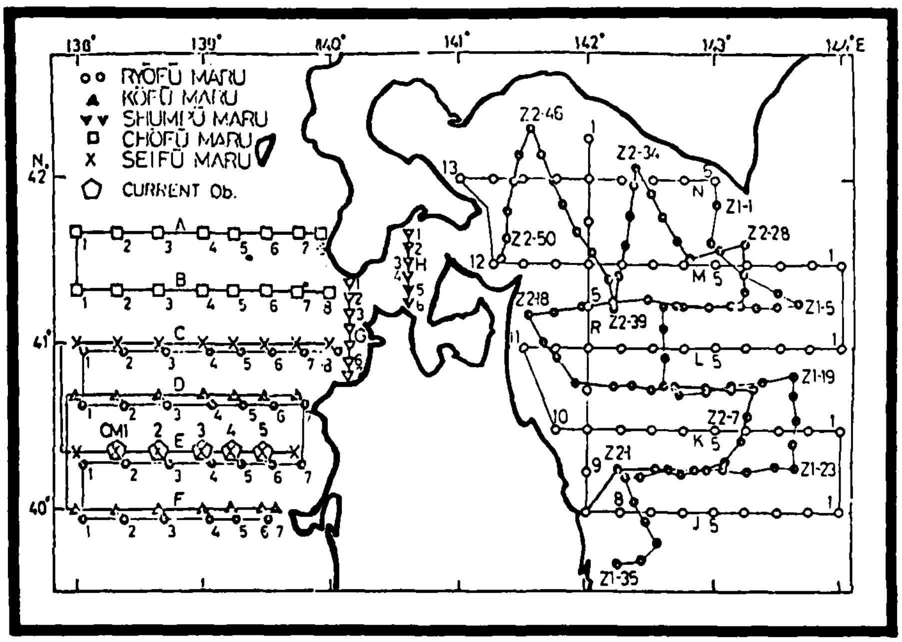


Figure 2. JMA 5-ship stations.

(Science & Techn. Agency, 1971)

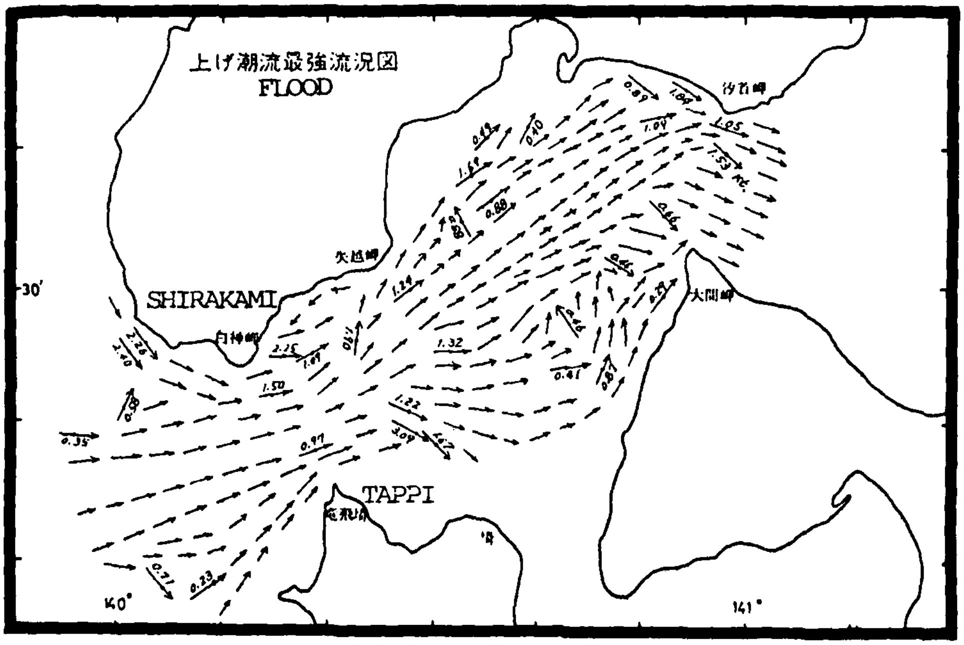


Figure 3. Tidal current at Tsugaru Strait.

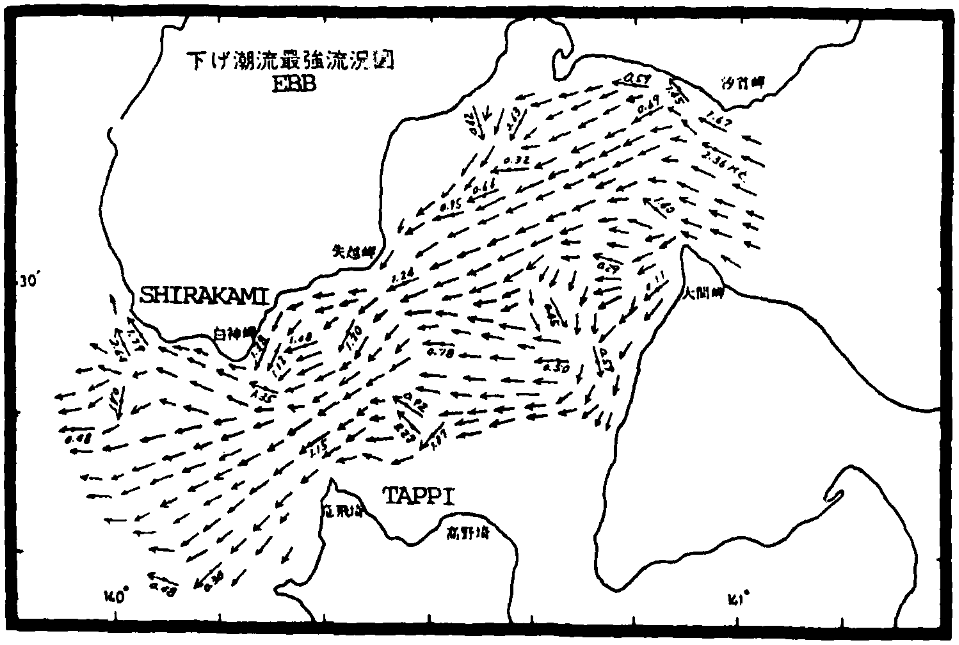


Figure 4. Tidal current at Tsugaru Strait.

(Science & Techn. Agency, 1971)

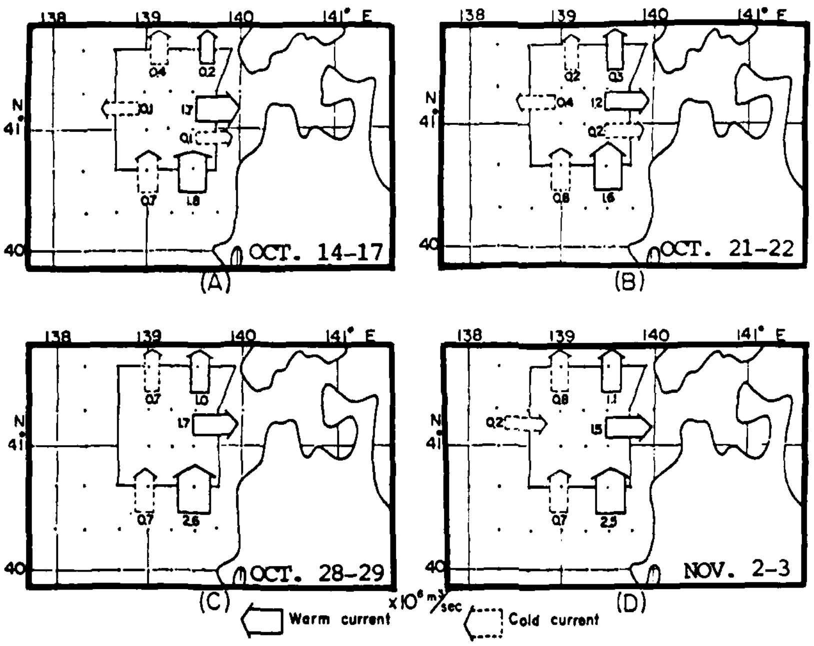


Figure 5. Volume transport calculations.

Unit: $\times 10^6 m^3/sec$

SECTION	Run 1			Run 2			Run 3			Run 4		
	W	C	Sum	W	C	Sum	W	C	Sum	W	C	Sum
South (40°40'N)	+1.8	+0.7	+2.5	+1.6	+0.8	+2.4	+2.6	+0.7	+3.3	+2.5	+0.7	+3.2
East (139°45'E)	−1.7	−0.1	−1.8	−1.2	−0.2	−1.4	−1.7	0	−1.7	−1.5	0	−1.5
North (40°40'N)	−0.2	−0.4	−0.6	−0.3	−0.2	−0.5	−1.0	−0.7	−1.7	−1.1	−0.8	−1.9
West (138°40'E)	0	−0.1	−0.1	0	−0.4	−0.4	0	0	0	0	+0.2	+0.2

+ INFLOW, - OUTFLOW W: WARM C: COLD

Table 1. Volume Transport Calculations.

(Science & Techn. Agency, 1971)

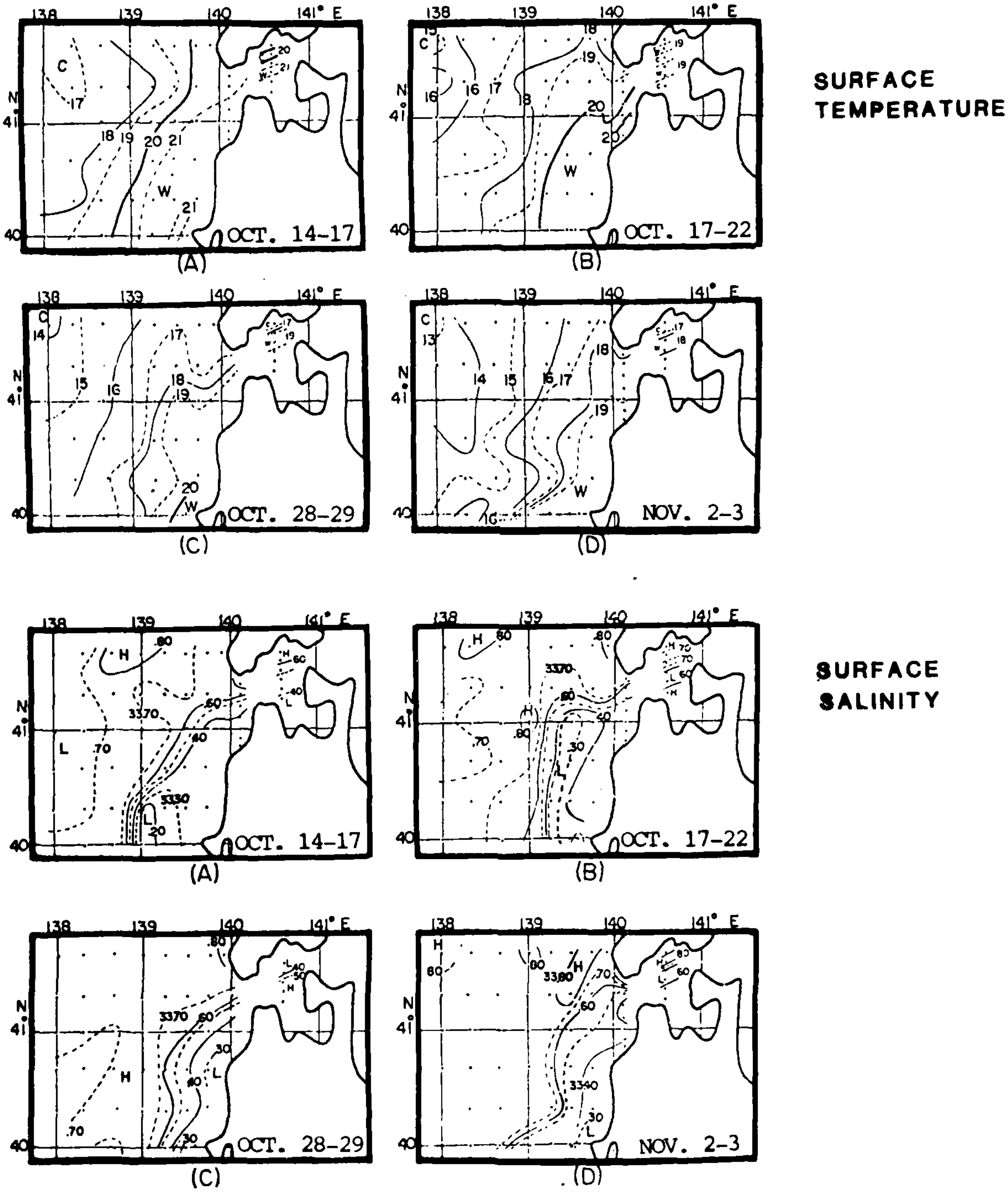
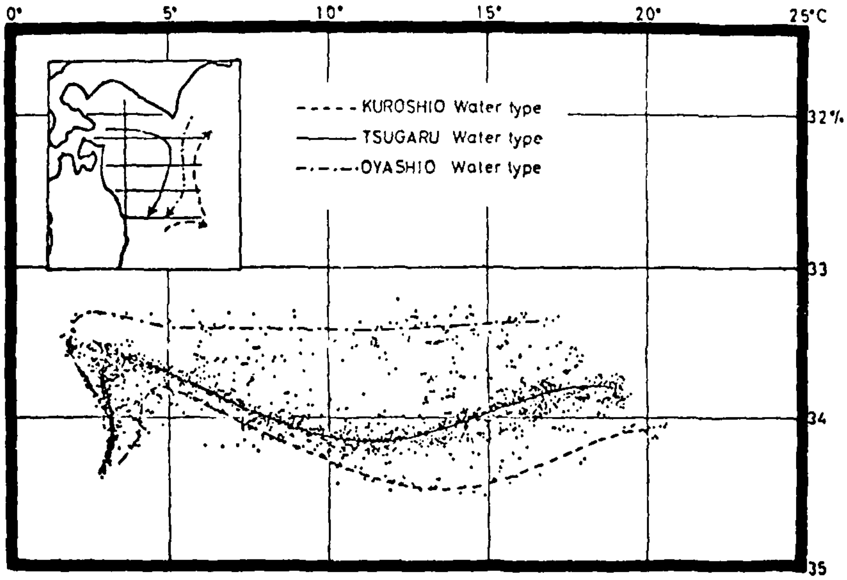


Figure 6.

(Science & Techn. Agency, 1971)



Temperature - Salinity correlations of water in the TSUGARU warm current area in Oct. 14 to Nov. 1 1970

Figure 7.

(Science & Techn. Agency, 1971)

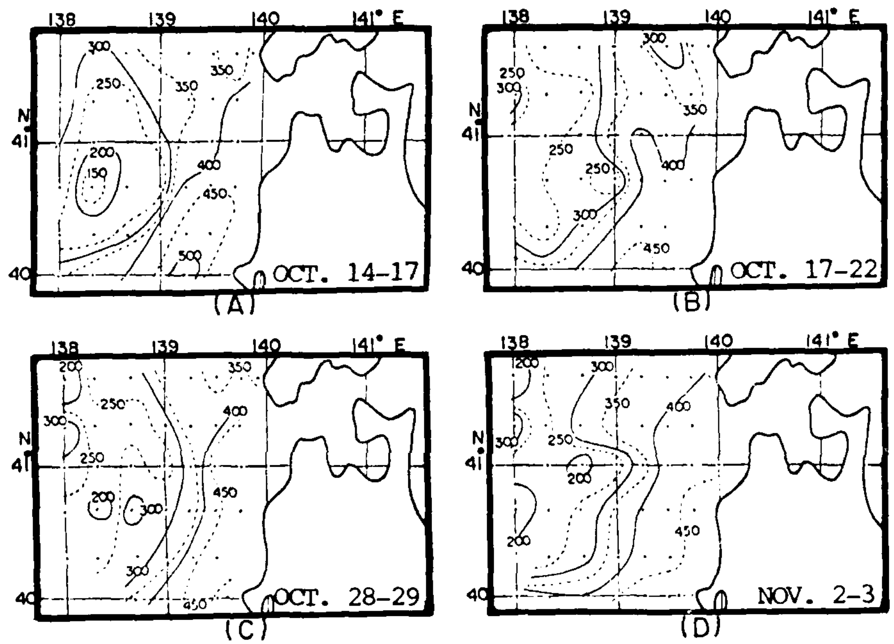


Figure 8. Depth of Japan Sea Original Water

(Science & Techn. Agency, 1971)

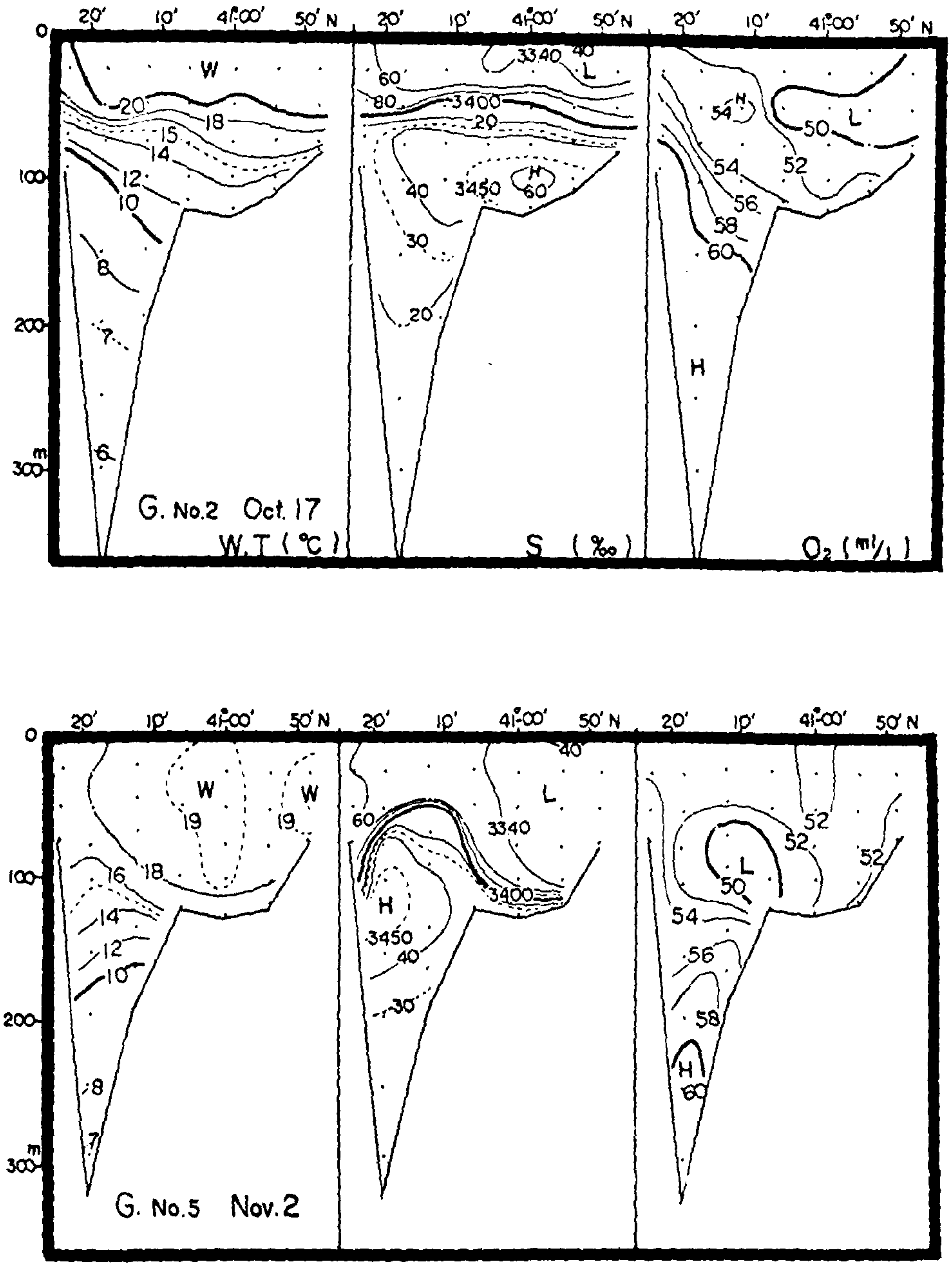


Figure 9. Hydrographic sections off West Entrance to Tsugaru Strait, 1970.

(Science & Techn. Agency, 1971)

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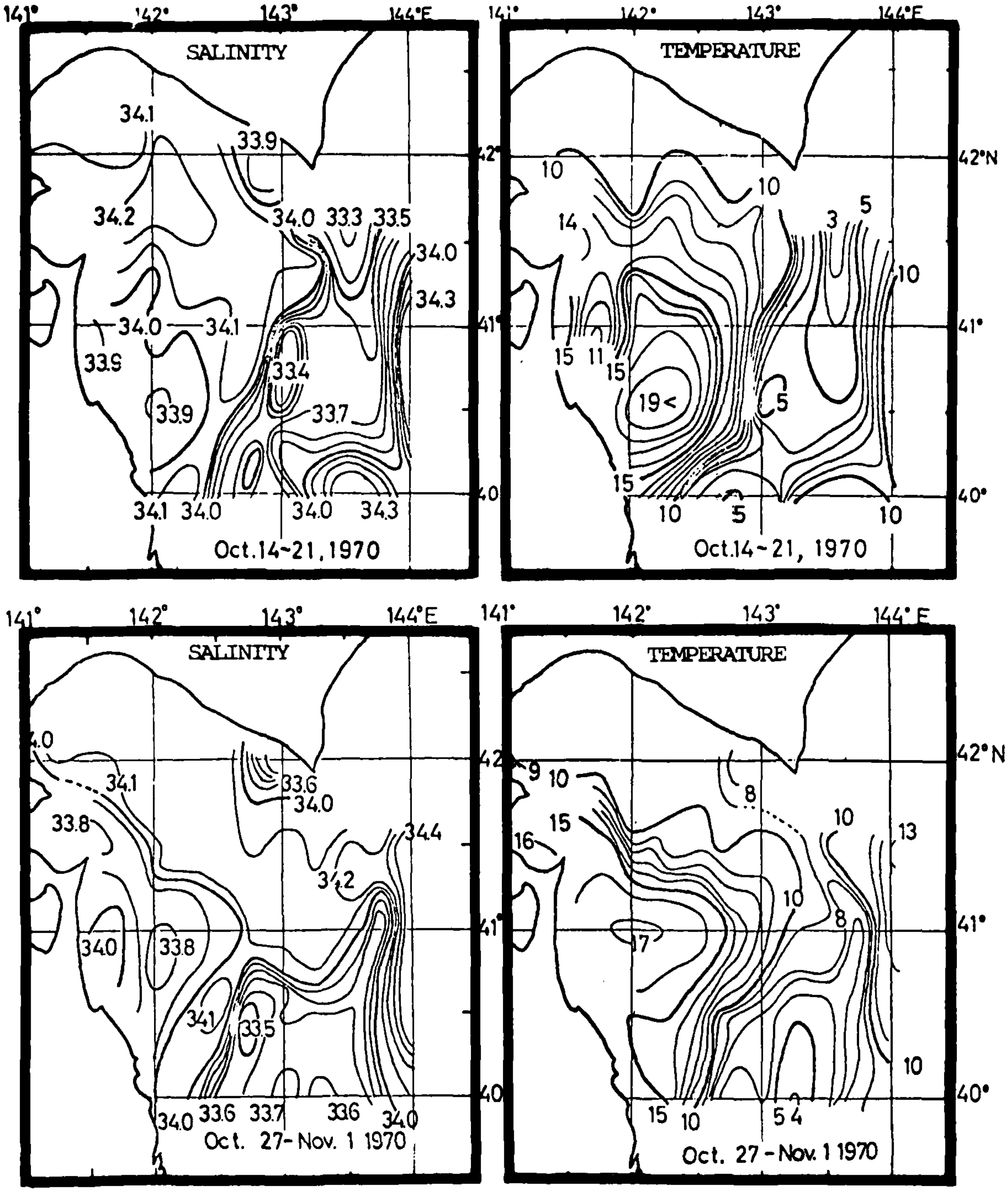


Figure 10.

(Science & Techn. Agency, 1971)

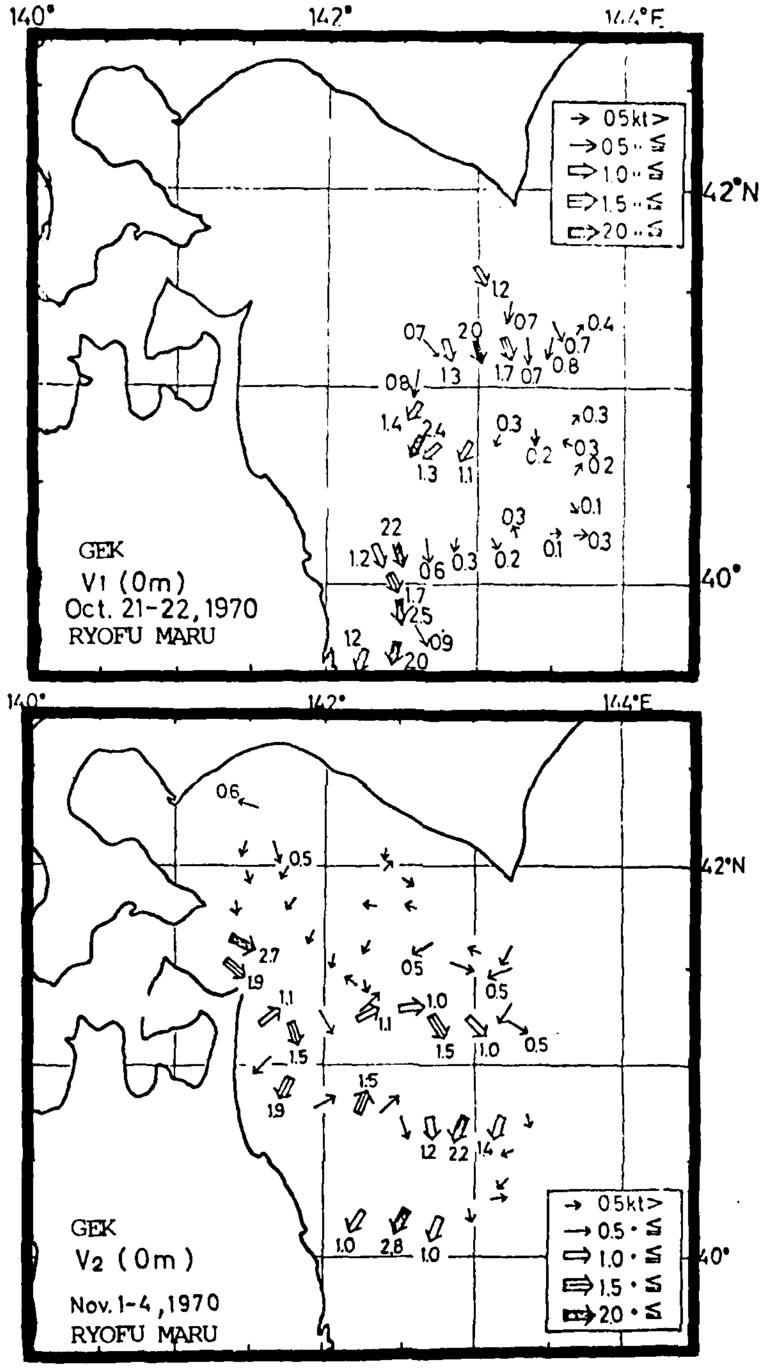


Figure 11.

(Science & Techn. Agency, 1971)

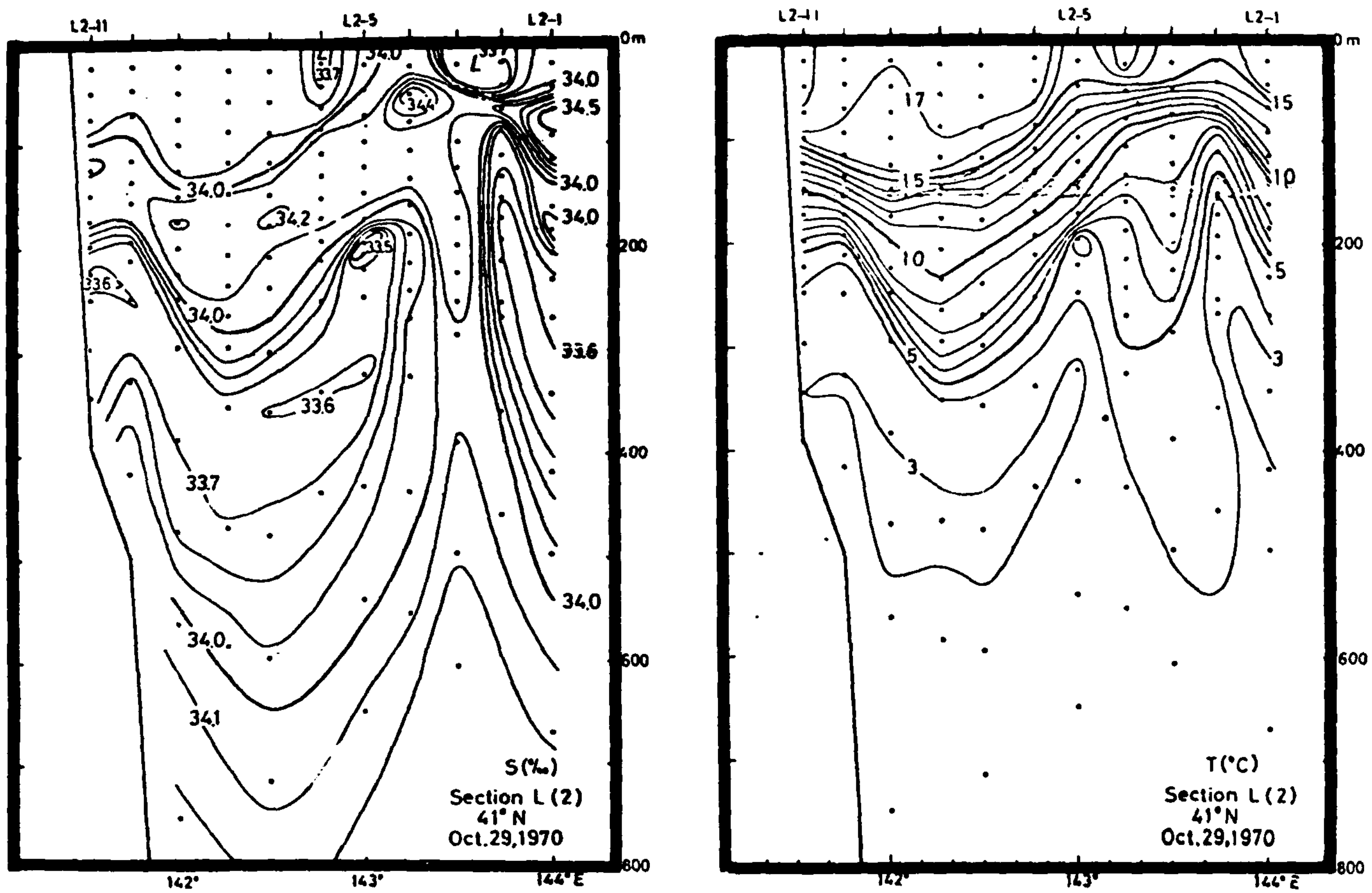


Figure 12. Hydrographic section across the Tsugaru Warm Current Extension.

(Science & Techn. Agency, 1971)

in the summer, 1947, when the arriving volume was 5.7 Sv, but was only 60% in the summer, 1950, when the latter was 2.0 Sv. The highest observed ratio was 93% in 1961 when the arriving transport was 3.2 Sv. Typical seasonal volume transports through the Tsugaru Strait based on dynamic calculations relative to 600 db for the entire study period 1933 - 1967 were: 1.7 Sv (winter), 1.8 Sv (spring), 4.4 Sv (summer) and 4.0 Sv (fall). See Figure 1 depicting various current patterns in the vicinity of the Tsugaru Strait. This paper supercedes a previous paper by the same author titled:

> Hata, K., 1962. Seasonal variation of volume transport in the northern part of the Japan Sea. Journ. Oceanographical Soc. of Japan, 20th Anniversary volume, pp. 168-179.

Science and Technology Agency, 1979. Report on the comprehensive study of the Tsugaru Warm Current region (Japanese with English abstract). Special Report of Science and Technology Agency, Japanese Governments, 335 p.

A 3-year study as a joint program between the Hydrographic Office, the Meteorological Agency, the Fisheries Agency was performed from 1975 to 1977, with the following objectives:

- o Currents in Tsugaru Strait (JHO).
- o Bottom topography and submarine geology in the Strait (JHO).
- o Oceanographic structure in the Tsugaru Warm Current region and relationship between fluctuation of oceanographic factors and meteorology (JMA).
- o Relationship between distribution and migration of fishing grounds and fluctuation of oceanographic factors.

The JHO concentrated on the currents at the western entrance, occupying a total of 27 stations over a 3-year span in the channel. Harmonic analyses on tide and tidal currents were performed on the data. The JMO's interest was mainly in the eastern region of the strait, with particular attention to the extension of the Tsushima Warm Current into the Pacific Ocean.

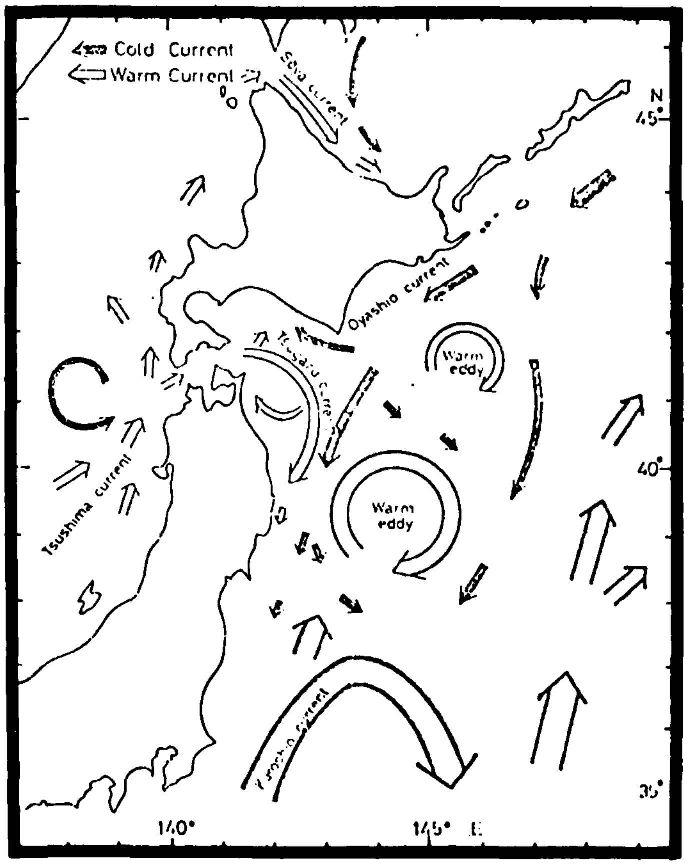


Fig. 1. Schematic representation of the hydrographic conditions in the neighbourhood of the Polar Frontal Zone

Figure 1. Hata (1973).

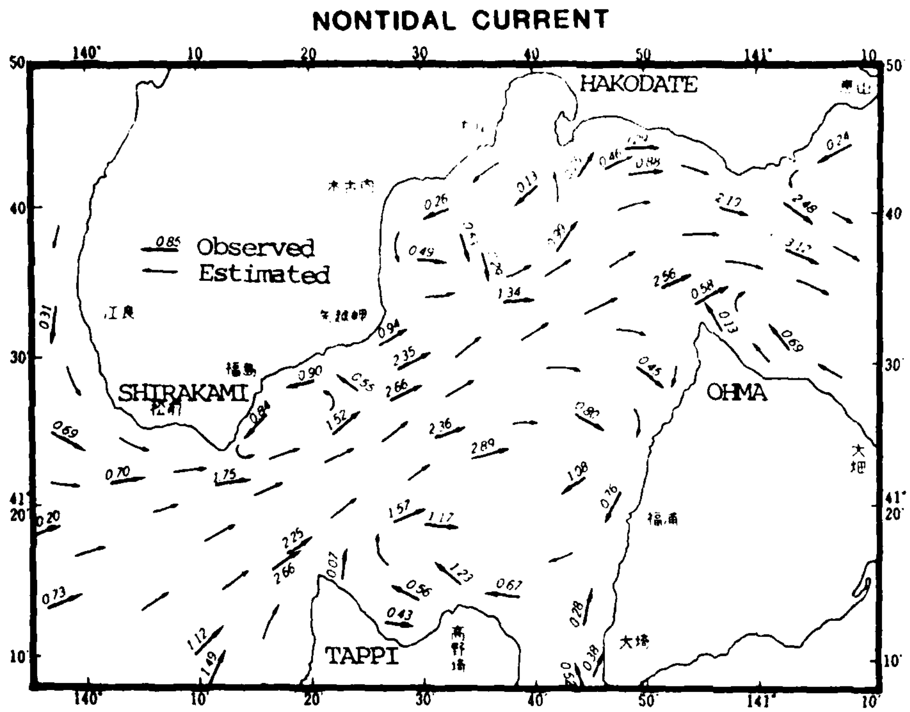
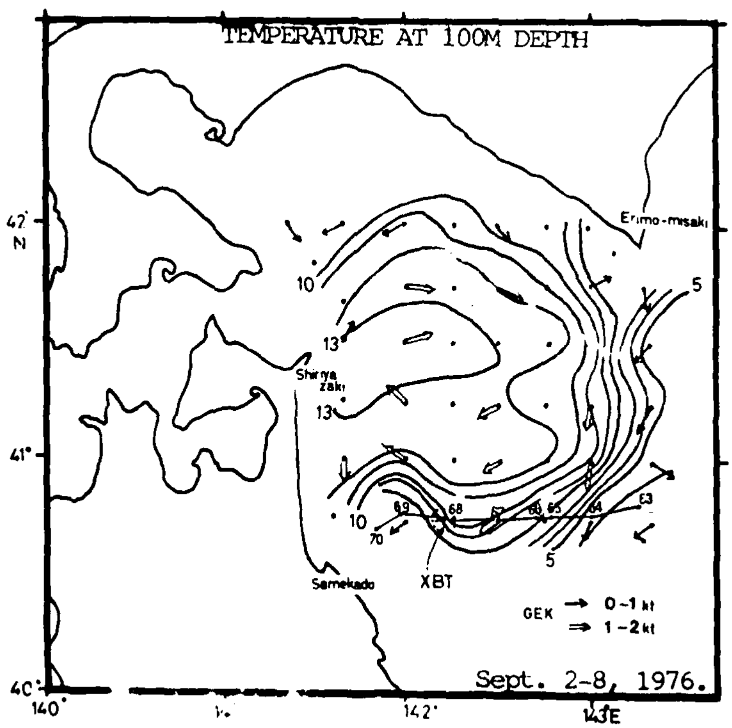


Figure 1. (Science & Techn. Agency, 1979).



gure 2. (Science & Techn. Agency, 1979).

Conlon, D.M., 1981. Dynamics of flow in the region of the Tsugaru Strait. Coastal Studies Institute Technical Report No. 312, Louisiana State University, Baton Rouge, Louisiana, 61 p.

Dynamics at the inflow, the channel and the outflow regions of the Tsugaru Strait were investigated using recent data from Japanese and U.S. sources. The volume transport into the strait was found to exhibit an excellent correlation with the steric height relaxation in the cross-channel, rather along-channel, direction in the inflow region adjacent to the entrance. In the channel itself, the flow was geostrophically balanced in the cross-channel direction, whereas the principal momentum balance was between the barotropic pressure gradient, the longitudinal baroclinic pressure gradient, and friction. The outflow exhibited two distinct model behaviors: a gyre mode (warmer months) and a coastal mode (colder months). The governing factor for these behaviors appeared to be the internal Rossby radius of deformation - a finding consistent with the results of a laboratory experiment by Whitehead and Miller (1979).

5.4 Soya Strait

Hakodate Marine Observatory, 1944. Report on Marine Observations in Soya Strait (Japanese with English abstract). Bull. Hakodate Marine Observatory, Vol. 1, pp. 1-62.

This report describes Japan's first major study on the Soya Strait, conducted by Yushio Maru in August 1942.

Figure 1 shows the stations occupied by Yushio Maru in 1942. The ship encountered a strong current (easterly flowing) in excess of 4 knots near Nijo-iwa, too strong to stay on anchor. Subsequently, the ship occupied Stations 17 and 18, where the highest recorded currents over a 24-hour period were, respectively, 155.0 cm/sec and 83.3 cm/sec, both flowing in the southeast. Figure 2 shows the tidal ellipses and non-harmonic components, indicating that the currents through the strait are dominated by non-harmonic rather than tidal effects. Maximum currents by tide alone were of the order of 40 cm/sec, whereas those by non-harmonic effects were of the order of 70 cm/sec.

Figure 3 shows the distributions of temperature and salinity at 0, 25 and 50-meter depths, and Figure 4 those in vertical sections. Notice the presence of a localized cold water mass hanging to the east of Nijo-iwa in Figure 3, which probably represents a topographically controlled upwelling in the wake of the island. Notice also, in Figure 4, that the isotherms have emerged to the surface in the vicinity of Nijo-iwa, i.e. between Stations 11 and 18, and again between Stations 11 and 12. Figure 5 shows dynamic topography.

Akagawa, M., 1968. The mean sea surface temperature of the Okhotsk sea in cooling season (Preliminary report) - Normal distribution of sea surface temperature.

Analysis is made of 5-day mean SST data during 1960-65 which incorporates the USSR maritime broadcast, to elucidate the role of the extension of the Soya Warm Current into the Sea of Okhotsk during the cooling season (October through December). The SST is higher in the southwest part of the Sea of Okhotsk and lower toward the northern part. The presence of warmer water extending to the midst of the Sea of Okhotsk is due to the Soya Warm Current which moves north- and northeastward as far as 50N after leaving the northern coast of Hokkaido. On the other hand, the East Sakhalin Current, moving southward along the east coast of Sakhalin, brings low-temperature and low-salinity water to the offshore region of Hokkaido.

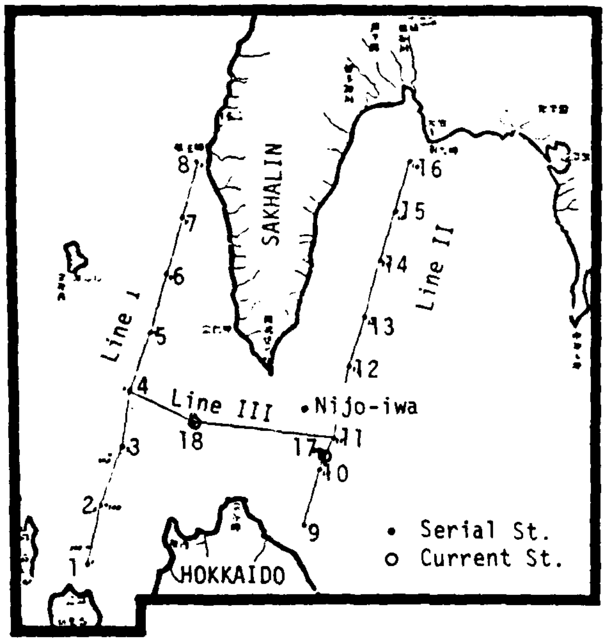


Figure 1. Oceanographic Stations, Soya Strait.

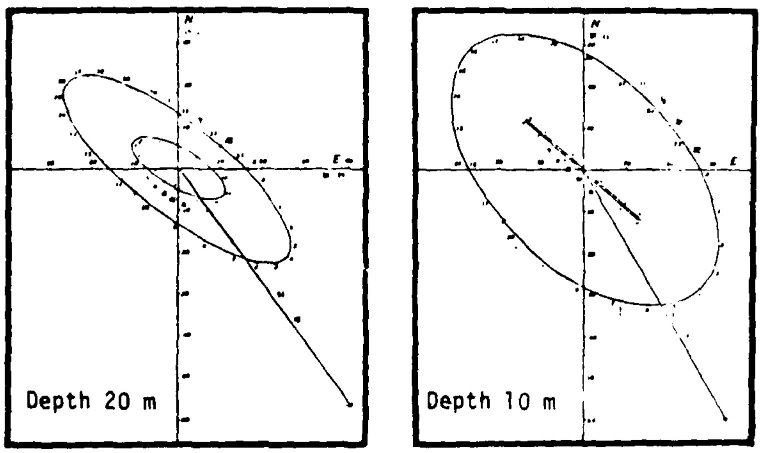


Figure 2. Tidal ellipses for currents at Station 17.

(Hakodate Marine Ob., 1944)

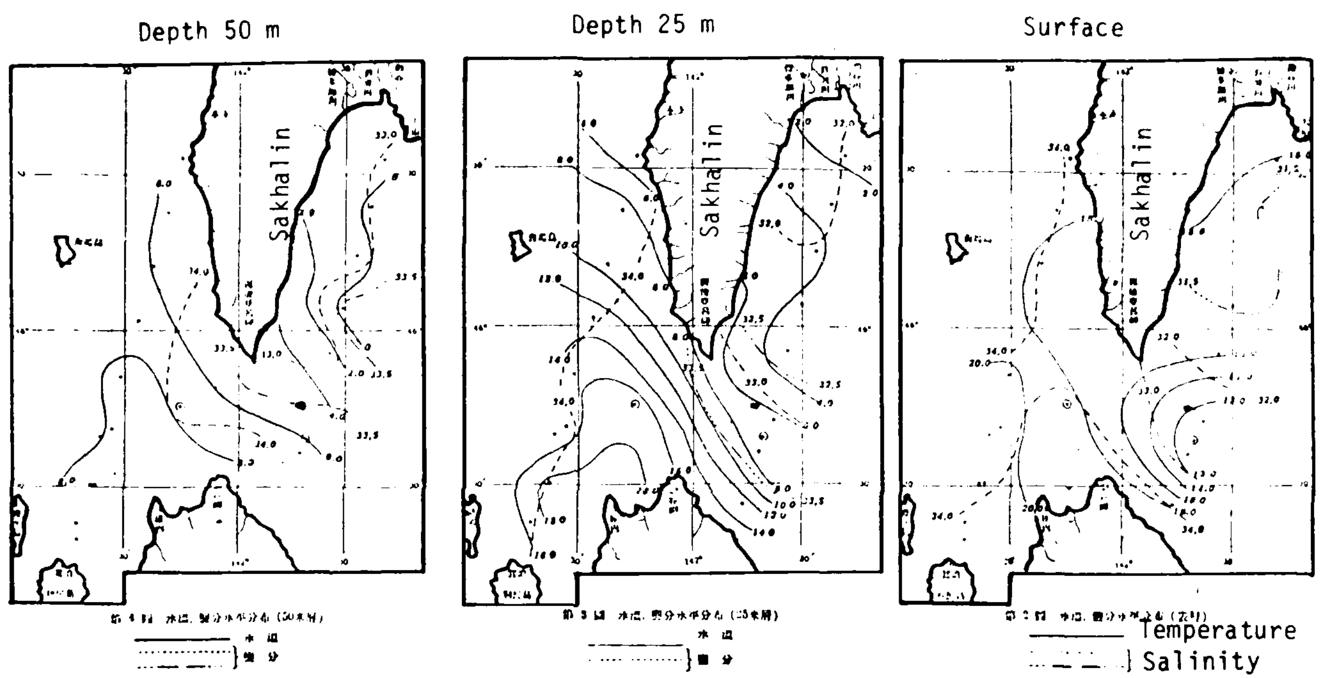


Figure 3. Temperature and salinity distributions in Soya Strait, August 1942.

(Hakodate Marine Obs., 1944)

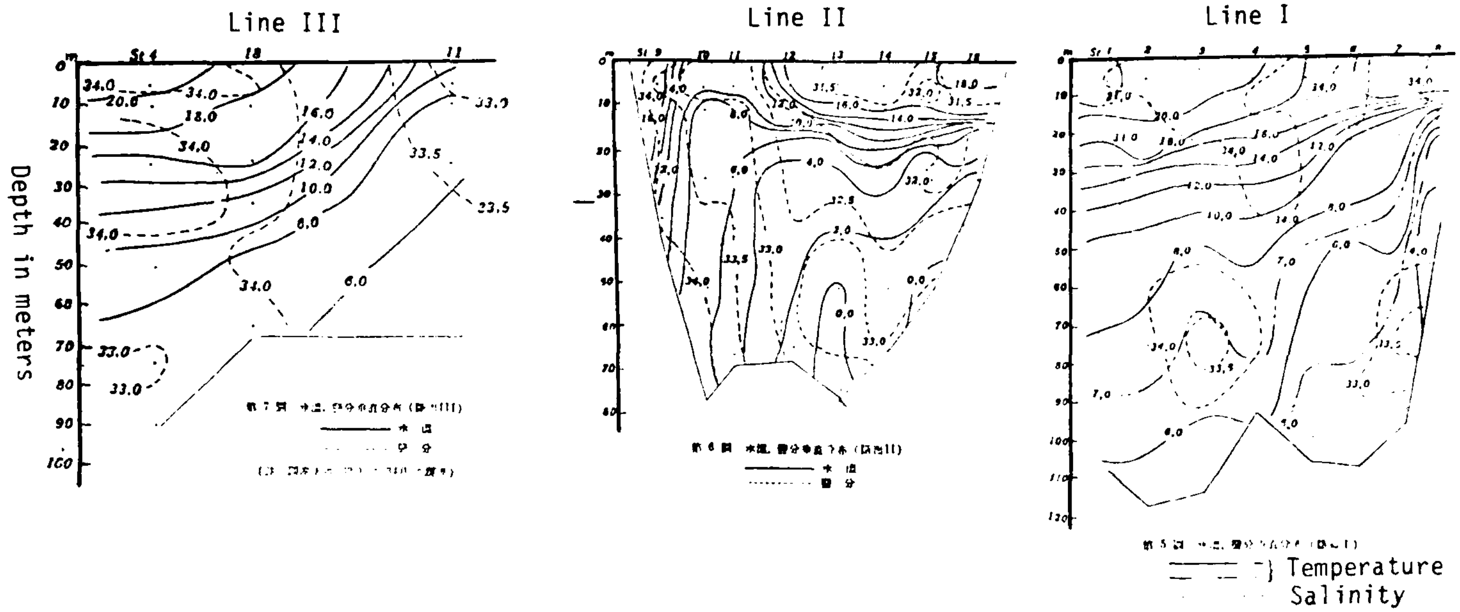
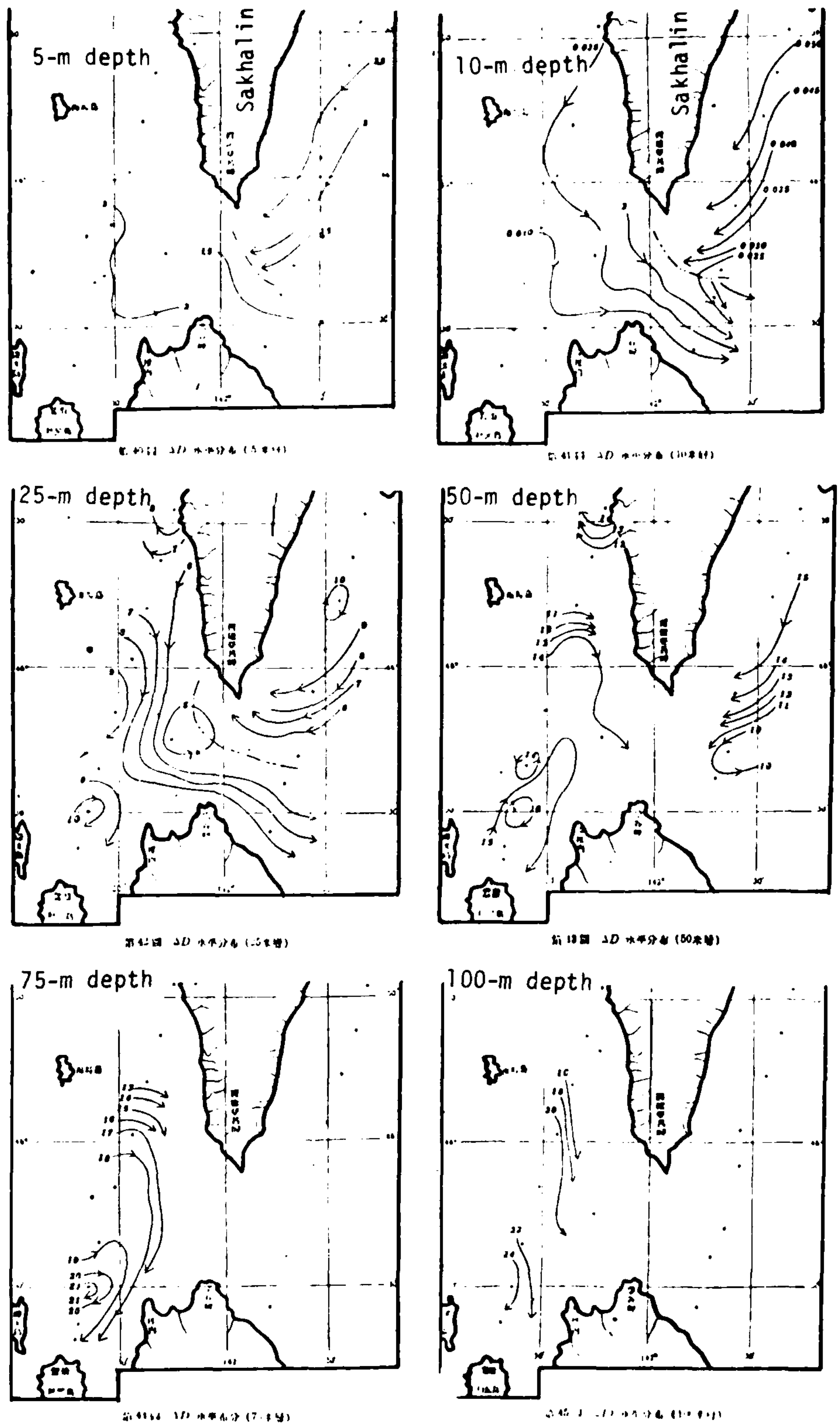


Figure 4. Temperature and salinity sections at Soya Strait, August 1942.

(Hakodate Marine Abs., 1944)

Figure 5. Dynamic topography at Soya Strait, August 1942.
(Hakodate Marine Obs., 1944)



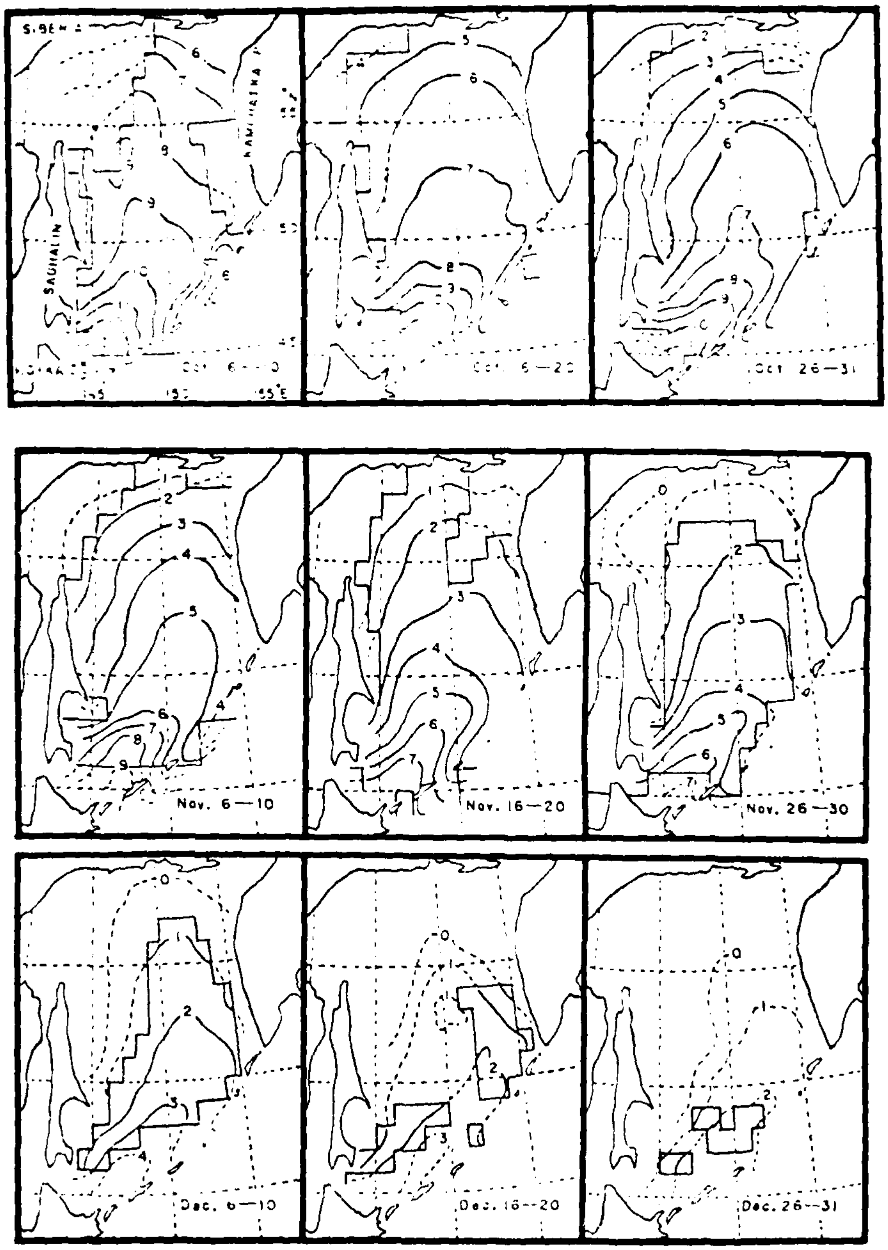


Fig. 1. Normal distribution charts of sea surface temperature.

(Akagawa, 1968)

1975年1月28日8時59分，網走沖の
流氷分布（円の間隔：5浬）

Figure 1.

(Karamura et al, 1975)
Radar imagery at 08:59,
Jan. 28, 1975.

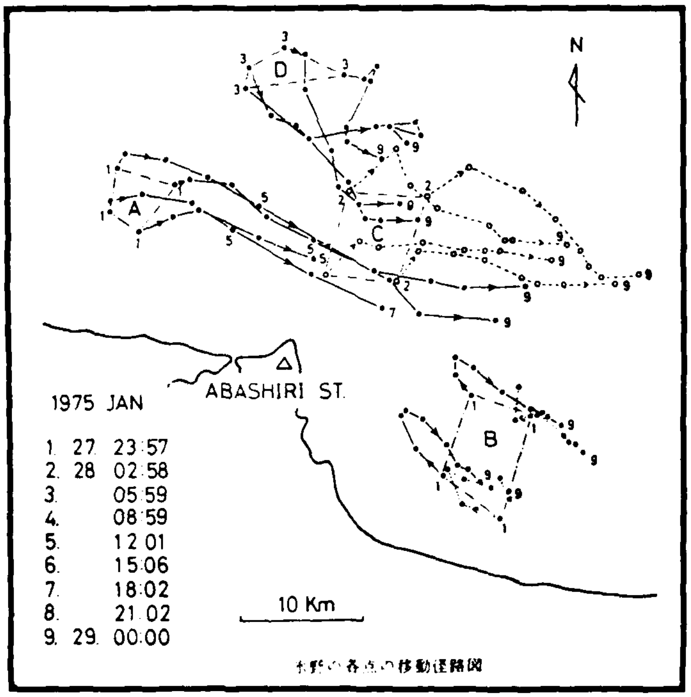


Figure 2. (Kawamura et al, 1975)
Trajectories of drift ice.

Maeda, S., 1967. On the cold water belt along the northern coast of Hokkaido in the Okhotsk Sea. (Hydrography of the Okhotsk Sea, Part I) Umito Sora, 43, pp. 19-37.

This study investigates the cause for the formation of a cold water belt which emerges along the offshore margin of the Soya Warm Current off the northern Hokkaido coast. Using oceanographic data from the Hydrographic Office during 1955-60 and more than 4,000 weather charts, the author proposes that the cold water belt is formed on the surface as a result of an upwelling of the dichothermal water (lying at 50 - 100 m below the surface) under the coast-parallel southeasterly wind which prevails during summer months. The author also discusses the lag time of the upwelling process under wind forcing.

Kawamura, T., M. Aota and T. Tabata, 1975. On the divergence and rotation of ice field off Okhotsk Sea coast of Hokkaido, (Japanese with English abstract). Low Temperature Science, Ser. A. 33, pp. 179-190.

Kawamura, T., 1977. On divergence and rotation of ice field off Okhotsk Sea coast of Hokkaido, II, (Japanese with English abstract). Low Temperature Science Ser. A. 35, pp. 259-266.

Drifting ice serves as an excellent indicator of surface currents in the Soya Warm Current region off the northern Hokkaido coast. Using a radar imagery at appropriate time intervals, ice movements were traced and their dynamic patterns analyzed. The velocity, divergence and rotation changed remarkably with time and space, and no distinct relationship with the wind system was recognized.

Science and Technology Agency, 1981. Report on the comprehensive study of the Sea of Okhotsk (Japanese with English abstract).

This 3-year program involved the Hydrographic Office, the Meteorological Agency, and the Fisheries Agency between 1976 through 1978, with the following main objectives:

- o Dynamics of the Soya Warm Current, the East Sakhalin Current, and the inflow through the Kurile Islands.
- o Development of cold water.
- o Interaction of oceanographic factors and biological productivity.

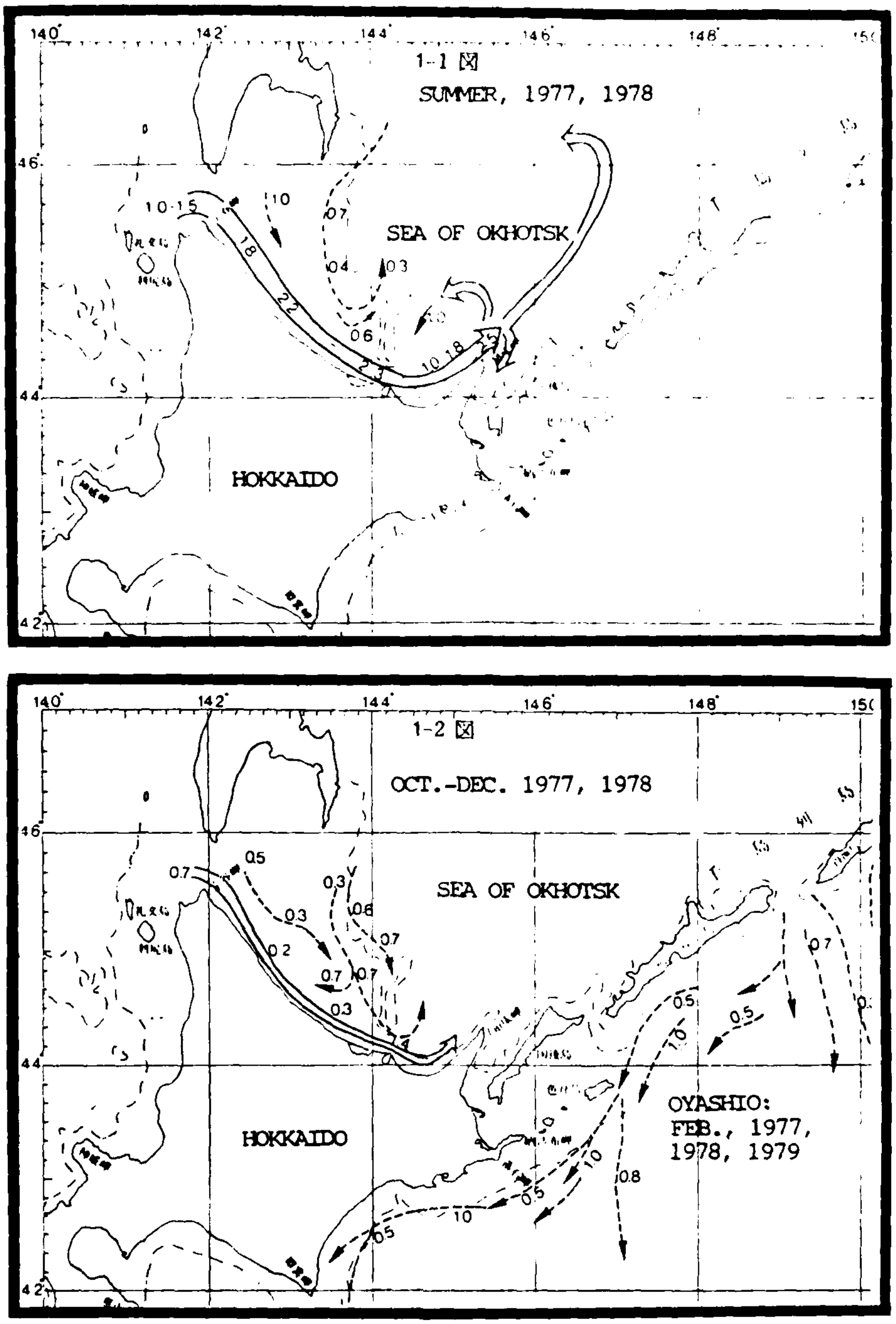
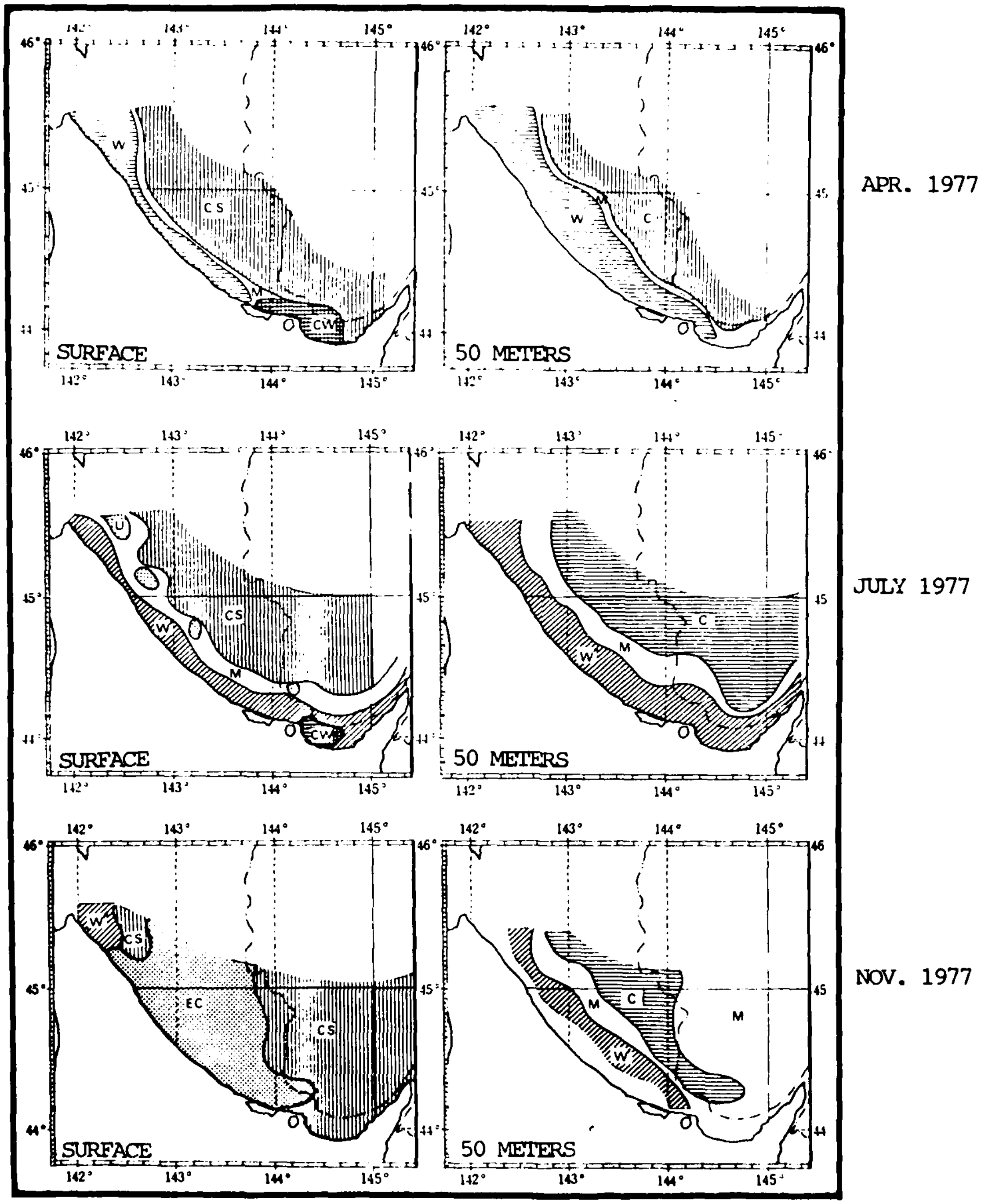


Figure 1. (Science and Techn. Agency, 1981).



W = Soya Warm Current Water
CS = Okhotsk Surface Water
M = Mixed Water
CW = Coastal Water

Figure 2. (Science and Techn. Agency, 1981).

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Data inventory, Tsushima Strait, Tsugaru Strait, Soya Strait, East China Sea, Sea of Japan, Sea of Okhotsk, Descriptive oceanography and Annotated bibliography.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In order to consolidate existing oceanographic data relating to the Tsushima, Tsugaru and Soya Straits, various data sources have been investigated and the results compiled into the cruise inventory data base of "Oceanographic Environmental Reference Service" system of NAVOCEANO. As of this report, a total of 2,025 cruises by Japanese data collectors have been inventoried.

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20. Abstract (Cont'd)

The purpose of this study is to provide (1) data directory information on the three Japanese sea straits to managers and planners, and (2) a referral guidance for those who wish to access or retrieve data. For this purpose, in addition to compiling an OERS data base, the report provides an extensive descriptive oceanography and an annotated bibliography. It also includes three appendices giving cruise track charts by the Japan Hydrographic Office, the Japan Fisheries Agency, and the Japan Meteorological Agency.

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